Final Report

Transportation in Megacities

A Comparative Analysis of Sustainability in Developed and Developing Economies

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Chapter 1. Introduction

Historically, motorization and its accompanying congestion, oil dependency, and air pollution have plagued the megacities of the developed world. Today, however, motor vehicles and the adverse effects of their intensive use have spread worldwide. In the last two decades, there has been a relentless growth in motor traffic, particularly that generated by cars, worldwide. In many cities, especially those in the developing countries, the transport infrastructure has been unable to cope with this upsurge in traffic. Traffic congestion has become a common sight and a problem that the commuters have to put up with every day. Reduced vehicle travel speeds lead to longer travel time, extra fuel consumption, extra air pollutants, extra discomfort to road users, and degradation of urban environment. To provide an efficient and environmentally-sound transport system is now a matter of great urgency in these cities, without which it would be difficult to achieve quality urban life for the inhabitants and to sustain economic growth.

Transport systems in megacities of the developing economies as compared to the developed economies is characterized by: (a) much lower level of motorization of transport and travel requirement, (b) more rapid rates of economic growth, population growth, and the growth in motorization, (c) higher population densities, (d) much lower per capita energy consumption, (e) much reduced access to capital and to advanced environmental technologies. Despite the much greater level of vehicle ownership, higher rate of trip generation and per capita energy consumption in cities of developed countries, it is the large cities in the developing countries that, in general, suffer most from growing traffic congestion, road accidents, energy use, air pollution, overcrowding of public transport and poor conditions for pedestrians and cyclists.

Trends in world motor vehicle registration

At present, the vehicle fleet is concentrated in the high-income economies of the world. In 1988, the Organization for Economic Cooperation and Development (OECD) countries[1] alone accounted for 80% of the world's cars, 70% of trucks and buses. The global population of motorized two- and three-wheeled vehicles (motorcycles and rickshaws) is not known, although they account for a substantial part of the motorized vehicle fleets in developing countries. In India, for example, two- and three-wheelers accounted for 70% of the registered motor vehicle fleet in 1991 (*ACMA, 1993*). Since 1950, the global vehicle fleet has grown tenfold and is expected to double within the next 20 years from the present total of 630 million vehicles (*Faiz, etal., 1990*). The rate of growth of world's vehicle fleet is projected to surpass that of both the total and urban population as shown in Figure 1.1.

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[1] OECD countries include the United States, Canada, most European countries, and Japan.

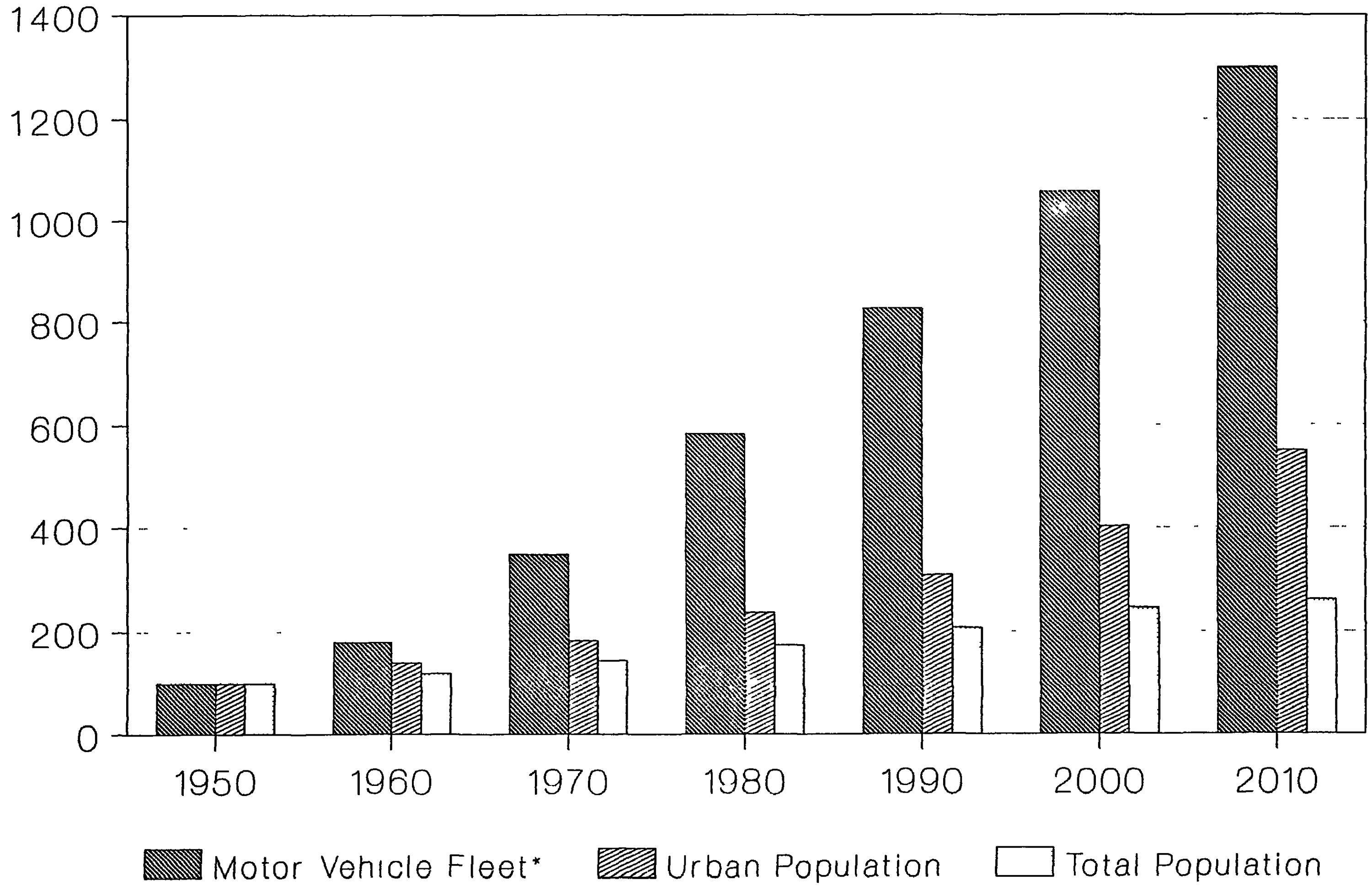
Much of the expected rapid growth of motor vehicles is likely to occur in developing countries and in Eastern Europe. For example, a tripling of the vehicle fleet is expected in China in the decade 1990 to 2000. Similarly, in India over twofold increase in vehicle numbers is expected during the same period - from 21 million to 43 million In contrast much of the demand for motor vehicles in the developed countries will be for vehicle replacement. As motor vehicle ownership approaches saturation levels in North America, Western Europe and Japan, most growth will be in developing countries and vehicle modes which have tended to get less attention such as two- and three-wheelers will be more and more important. The dramatic increase in growth of personalized vehicles is making unrestricted claims on valuable road space and energy resources, on the one hand, while congestion/air pollution on the other.

Two decades of transportation energy demand

Table 1.1 summarizes commercial energy demand by different sectors and by broad geographical/socio-economic regions worldwide for two years - 1971 and 1990 (*IEA, 1993*). Currently, transportation accounts for about one quarter of the global commercial energy consumption, and for about 43% of oil consumption. Perhaps the most notable dynamic trend between 1971 and 1990 is the dominance of transportation energy consumption in total demand growth in the OECD countries. During the same period, around two thirds of additional energy demand growth is due to increase in mobility levels. However, in developing economies although the transportation demand growth is significant in both absolute and percentage terms, it accounts only for around 15% of additional energy demand. Considering the differences in population growth in developed and developing economies and based on the data presented in Table 1.1, the annual per capita energy consumption for mobility of goods and people varies from around 70 kilogram oil equivalent (kgoe) in developing countries to some 1900 kgoe in North America, i e., by nearly a factor of 30 (*Grubler, 1993*). Thus, even though population growth rates are higher in developing countries, the increase in per-capita consumption level is a more powerful influencing variable than population growth per se.

Rising incomes combined with an increasing propensity for personal mobility and travel is likely to result in a pronounced increase in automobile ownership and bus transportation in much of Asia, Middle East, Eastern Europe and parts of Africa. Looking across different income levels and individual lifestyles, disparities in per capita energy consumption are likely to be even higher. Such disparities not only exist between different countries but also within countries. Transportation energy demand differences between the

Fig.1.1. Growth of population and motor vehicle numbers (1950-2010)



*Excluding two- and three-wheelers

Source: Faiz, A., etal 1990

Table 1.1. Final (commercial) energy demand by sector and world region, 1971 and 1990, in million tons oil equivalent (Mtoe) and average annual growth rates (percent/year)

	Industry	Transport	Residential & Commercial	Total	Transport share out of total (%)
1971					
OECD-North America	499	392	456	1347	29%
OECD-Europe & Pacific	518	199	336	1053	19%
Eastern Europe & ex-USSR	430	112	243	785	14%
Developing countries	145	110	312	567	19%
World	1592	813	1347	3752	22%
1990					
OECD-North America	542	526	461	1529	34%
OECD-Europe & Pacific	527	372	443	1342	28%
Eastern Europe & ex-USSR	577	167	420	1164	14%
Developing countries	681	287	702	1670	17%
World	2327	1351	2027	5705	24%
Average annual growth rate (%/year)					
OECD-North America	0.44	1.56	0.06	0.67	74%
OECD-Europe & Pacific	0.09	3.35	1.47	1.28	60%
Eastern Europe & ex-USSR	1.56	2.12	2.92	2.09	15%
Developing countries	8.48	5.18	4.36	5.85	16%
World	2.02	2.71	2.17	2.23	28%

Source: *IEA, 1993.*

urban elites and subsistence level rural farmers in developing countries will be much larger than differences between income groups within countries or even cities in different countries.

Passenger transportation

The relationship between energy demand and passenger transport service requirements is more intricate than for goods transport. The main reason is the diversity of human activities resulting in mobility, and the complex nexus of values, preferences and resulting lifestyle variables influencing mobility levels. These variables influence which transport modes are chosen and how they are used. This can perhaps be best illustrated by analyzing the different reasons for individual mobility in the United States (one of the countries with the highest mobility levels) and a developing country like India. People in the United States travelled some 6.7 trillion passenger-km in 1990, or some 26,900 km per capita (*NPTS, 1990*), as against 0.28 trillion passenger-km, or 333 km per capita in India during 1991 (*Planning Commission, 1992*). It is perhaps surprising to note that less than 18% of all passenger-km in the United States are associated with commuting to and from the work place, whereas some 44% are associated with household and child care business. In 1990, nearly 2.5 trillion passenger-km were travelled in the U.S. for leisure purposes including vacations, seeing friends, and other social and recreational activities. Thus leisure travel in the U.S. is almost nine times the total travel of people in India although the latter has three times the population of the former. Further, public transport (buses and railways) in the developing countries (apart from their lower levels of per capita long-distance mobility) plays a dominant role in meeting travel demand instead of private automobiles in the OECD countries. Over time, in OECD countries, public transport has lost out to cars and air travel, implying that modal split changes have favored faster more energy intensive transport modes. For instance, more than 4 million cars were registered in the county of Los Angeles in the mid-1980s, with about 0.54 cars per inhabitant (*Newman and Kenworthy, 1989*). In such "automobile cities", the market niche for public transportation is obviously rather small.

Mobility in urban areas is of particular interest, because cities tend to focus both the functional and environmental problems inherent to transportation. Limits of space and high densities of land-intensive individual transport modes (cars, two-wheelers) result in congestion. Particularly, in megacities, high population density and concentration of trips, and limited capacity of the environment to assimilate emissions is most visible. The motor vehicles now constitute the main source of air pollutants in the majority of cities in developed countries. This is particularly true of the pollutants CO, NO_x, and, to a lesser extent, SPM, HC, SO_2. Even regions where most cars are already equipped with catalytic convertors (like Los Angeles) are notoriously plagued by smog. The cities of developing countries, in contrast, exhibit a greater variety of air pollution sources. The relative contributions of mobile and stationary sources to air pollutant emissions differ markedly among cities and depend on the level of motorization and the level, density, and type of industry present. However, in the cities of developing countries, vehicles are a significant source of airborne toxic pollutants, accounting for up to 95% of lead (*World Bank, 1992*).

Air pollution in megacities

Motorization is inextricably linked to urbanization. The concentration of population in very large conurbations has led to some of the world's worst congestion and air pollution. Air pollution contributes to respiratory ailments and declining ecosystems. Exposure to air pollution is now an almost inescapable part of urban life throughout the world.

Air pollutants emitted from gasoline vehicles include carbon dioxide (CO_2) arising from the combustion of fossil fuel, carbon monoxide (CO) and hydrocarbons (HC) resulting from incomplete combustion, nitrogen oxides (NO_x) generated at high combustion temperatures, and lead (Pb) from fuel in which lead is added to attain desired octane rating. Air pollutants emitted from diesel vehicles are CO_2, CO, HC but at rates lower than gasoline vehicles because of better combustion efficiencies, NO_x at a rate higher than gasoline vehicles because of lower combustion temperatures. Diesel vehicles emit no lead but emit fine particulates and higher levels of SO_2. These pollutants often exceed the WHO Guidelines in many large cities in developing countries such as Mexico City, Sao Paulo, and Santiago in Latin America; Ibadan and Lagos in Africa; nearly all the megacities in Asia (notably Bangkok, Delhi, Bombay, Jakarta, Manila and Seoul). Given the rate at which these cities are growing and the general absence of pollution control measures in many of them, air pollution will probably worsen, and the quality of life of many urban residents will continue to deteriorate.

As large oil consumers, motor vehicles are major sources of CO_2, volatile organic compounds (VOCs) and NO_x, the precursors to both tropospheric ozone and acid rain. All of these gases contribute to greenhouse warming either directly or indirectly. Globally, motor vehicles account for about a third of world oil consumption and about 14% of the world's CO_2 emissions (growing by about 2.5% per year) from fossil fuel burning (*MacKenzie and Walsh, 1990*). For the United States, the corresponding figures are 50% of the oil demand and about 25% of CO_2 emissions. Although ozone in the lower atmosphere does not come directly from motor vehicles, they are the major source of ozone precursors throughout the industrialized world. Scarcely a century ago, Los Angeles was a small city in the most productive U.S. agricultural valley. It is now a 450 square mile (1,200 square kilometer) network of roads and development (*U.S. Bureau of the Census, 1994*). With little public transportation, residents rely on automobiles: the region has perhaps the highest number of vehicles per person in the world, and daily commutes of 60-80 miles (95-130 kilometers) are not unusual (*GEMS, UNEP, and WHO, 1994*). Despite increasingly stringent control measures (e.g., cars are equipped with catalytic converters), smog[1] continues to plague residents both in the city and in outlying regions. The state standard for ozone was exceeded at all monitoring sites in 1990, and in some areas on more than 100 days in the year.

Figure 1.2 presents a subjective overview of the relative air quality situation in the 20 megacities (*GEMS, UNEP, and WHO, 1994*). To compare the cities, the following four categories were considered:

3 = serious problem: WHO guidelines exceeded by more than a factor of two;
2 = moderate to heavy:WHO guidelines exceeded by up to a factor of two;
1 = low pollution: WHO guidelines are normally met;
0 = no data available or insufficient data for assessment.

Obviously, such comparisons are very difficult owing to differences in monitoring methods, reporting procedures, and so forth. Figure 1.2 clearly shows that a high level of SPM is the major problem affecting the megacities as a group. It is most severe in those megacities where high concentrations of SO_2 occur simultaneously. Next in severity are levels of O_3, lead, and CO. Many of these cities must also be considered to have potentially serious NO_2 pollution; however the data are too incomplete to reveal levels that regularly exceed the WHO guidelines. Data for O_3 are even less complete. Nevertheless, it is clear that air pollution has escalated greatly in most of the megacities over the past decade because of rapid population growth, industrialization, and increasing energy use.

Four factors make pollution from vehicles more serious in developing countries. First, many vehicles are in poor condition, creating more particulates and burning fuels inefficiently. Certain types of engines, such as two strokes, are currently particularly bad, though new options for improving their efficiency and cleanliness will be available soon. These two stroke engines emit hydrocarbons and smoke up to ten times the rate of modern four stroke engines and produce vast majority of emissions. Second, lower quality of fuels are used, leading to far greater pollutants. Third, motor vehicles are concentrated in a few megacities. Fourth, a far larger percentage of the population moves and lives in the open air and is thus more exposed to automotive pollutants.

Projections of emission levels from passenger transport (only cars, taxis and buses) for a sample of ten large cities[2] in developing countries indicate a doubling or more of emissions by the year 2000, assuming modal shares remain unchanged from a 1980 base

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[1] primarily ozone (O_3) formed by the photochemical reaction of two motor vehicle exhaust emissions: NO_x and VOCs.

[2] include Bangkok, Bombay, Jakarta, Karachi, Seoul, Bogota, Mexico City, Rio de Janeiro, Cairo and Nairobi.

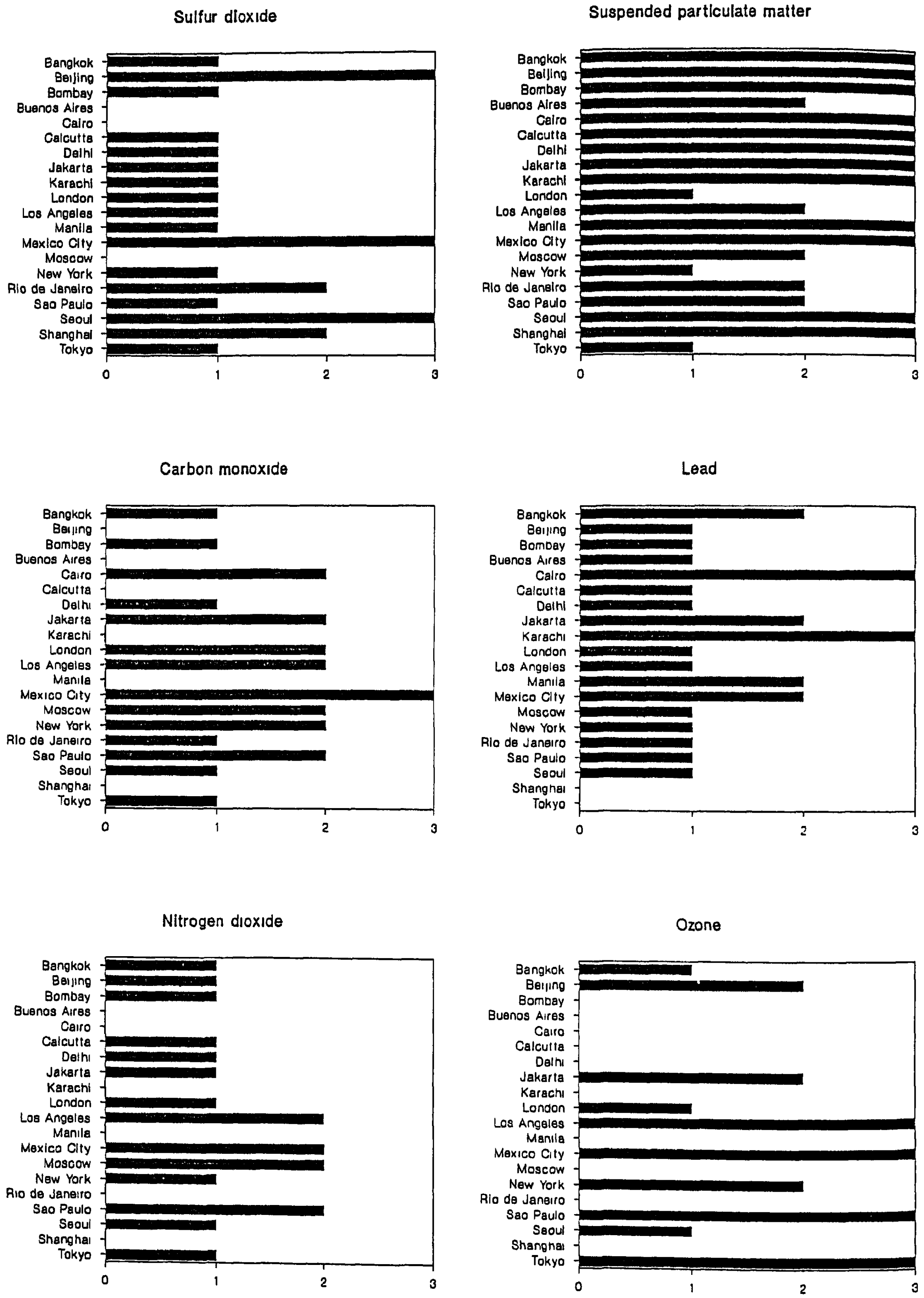


Figure 1.2 Air quality in 20 megacities

level (*Faiz, etal., 1990*). With the anticipated increase in automobile ownership and the heavy reliance on buses (often poorly-maintained) for public transportation, emission from motor vehicles could well be higher by a wide margin. If the present trend of vehicular growth continues, motor vehicle emissions - in terms of both urban air pollution and global warming - in many large cities in the developing world will be much worse than the projected levels for major cities in developed countries.

The OECD countries have had some success in controlling the main pollutants from motor vehicles. Increasingly, stringent regulations have led to changes in the design of engines, in emissions control devices, and the types of fuel used. Many of these developments have not yet been fully incorporated into the vehicle fleets, but the upshot has been a significant decrease in lead emissions and containment of other pollutants. In developing countries, leaded fuels are still widely used, and emissions standards are either nonexistent or are much slacker than in the OECD countries. Ultimately, the solution lies in building institutional capacity for transportation management in developing countries, while facilitating the co-development of advanced transportation systems by combinations of firms in the "North" and the "South".

It is therefore evident that strong policy interventions need to be initiated in larger cities of both developed and developing countries to curb the growth of energy demand in the transport sector and the resultant vehicular emissions. Further, there are important lessons to be transferred from developed to developing countries and *vice versa* regarding policies that will be effective in the transportation sector.

Other related studies

Unfortunately, no comparative studies are available between cities in developed and developing countries with respect to transportation energy demand and emissions. Whatever research is done in this area, looks at either comparison of cities among developed countries or among developing countries. The most comprehensive study by *Newman and Kenworthy* examines 60 cities from over 30 developed countries patterns of urban land use, travel pattern, and transport energy use (*1989*). In developing countries, a new approach to planning called integrated transport planning was carried out in 4 Asian cities by *Zegras and Birk* (*1994*). *Walsh* has summarized motorization and its adverse impact on air pollution based on 7 cities case study all in developing countries (*1994*). *Shimazaki, Hokao and Mohammed* developed a graphical model that analyzes the modal choice pattern in 19 Asian cities (*1994*).

Given this background, the study has made an attempt to seek answers to the following questions, based on sharing experiences from the tale of two megacities - Los Angeles in North America and Delhi in India.

1. What is the current energy demand in the transport sector and the resultant environmental impacts (local and global emissions)?
2. How will the changes under way -- in fuel use, technology and modes of transport -- affect environmental and energy resources?
3. What range of policy options are at present considered and implemented to steer metropolitan transport choices, and what is their success in altering trip patterns, reduction of traffic congestion and/or modal splits?
4. Which policies (by sharing experiences between developed and developing countries) are necessary in cities to provide more sustainable transportation services from an emissions and resource use standpoint?

It could be argued that the two cities are too different from one another, particularly in terms of their topography. There seemed to be a value in carrying out an international transportation study of megacities in developed and developing countries. While the conventional wisdom that developing countries that are modernizing have lessons to learn from the mistakes of developed countries viz., the environment, in the transportation field, cities in the advanced countries have a lot to learn from developing countries. For example, facilitating the shift from personal to public transport can significantly reduce the large disparities in per capita energy consumption levels. Conversely, developing countries need to have access to less polluting technologies and to learn from the success and failures of developed countries.

Organization of the report

The report is organized into five chapters, as follows: Chapter 1 deals with the principal differences between developed economies' and developing economies' with respect to the historical developments in the transport sector with special emphasis on the role of population growth with rapid urbanization, motorization and its impact on energy resource and emissions. The chapter also provides an air quality (subjective) profile for the 20 megacities located in both developed and developing countries Chapter 2 presents scope and objectives of the study. Chapters 3 and 4 present the two city case studies - Los Angeles and Delhi. These chapters focus on innovative urban transport plans and policies to reduce energy demand and mitigating emission strategies. Finally, Chapter 5 gives the alternative definitions of sustainability as the new focus of transport policy for developed and developing economies.

Chapter 2. Scope and Objectives

Two megacities in the United States (Los Angeles) and India (Delhi) are selected for a comparative analysis with respect to trends in transportation energy use and emissions of criteria pollutants, greenhouse gases, and other relevant environmental impacts, such as availability of land for infrastructure. Such a cross-comparative study of two megacities - Los Angeles and Delhi, would facilitate formulating a set of policy measures and implementing mechanisms on the basis of experience gathered from these cities, and for megacities in general. The goal of this comparative assessment is to identify options for cities of various levels of infrastructure development that would enable them to meet transport needs while minimizing environmental degradation, oil consumption, and traffic congestion. But more than that the study is expected to find out what implications the international comparisons have for future urban transport policy in developed and developing countries based on the lessons learned from successes and failures.

The objectives of this study is two-fold: First, the study has made an attempt to compare the two megacities (Los Angeles and Delhi) by,

- analyzing secondary information on changing demographic patterns, income levels, growth of vehicles and composition, ownership pattern, traffic congestion, occupancy, journey speeds, travel demand and modal spilt, volume of trips and trip length.
- estimating the present and future transport energy requirements by different modes of vehicle and the consequences to unsafe levels of urban air pollution, for changing demographic patterns;
- analyzing the various transportation strategies adopted in the two cities to study the overall impact on energy savings and reduction of vehicular pollution;
- formulating recommendations on energy-environment strategy in each of the two cities to mitigate adverse impacts of transportation network.

Second, on the basis of lessons learned from the two cases, the study has proposed alternative definitions of sustainability of urban transport for developed and developing economies. Finally, the study analyzes,

- what is likely to be necessary for improving efficiency and equity such as, use of alternative fuels and technologies and other changes required in the transportation system to achieve the sustainable path of urban development in developed and developing economies.

Chapter 3. Los Angeles

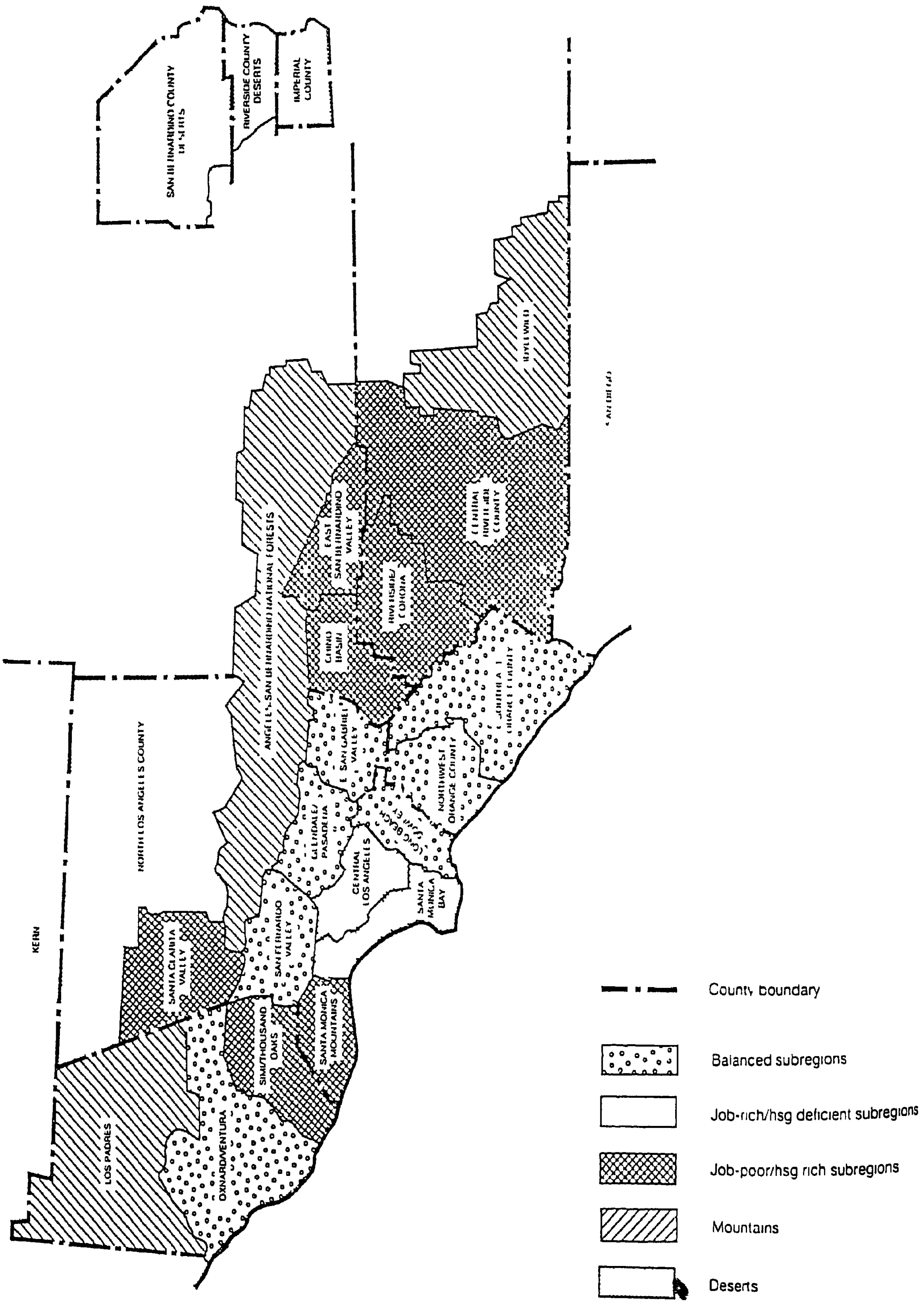
The Los Angeles region is characterized by a unique climate, topography, economy, and lifestyle. For example, its topography includes a narrow coastal strip and lush coastal valleys on the west, foothills and high rugged mountain ranges to the north and south, and inland deserts on the east. The coastal plains and valleys, although constituting a small portion of region's land area, contain the majority of the population and land devoted to urban activities. Los Angeles has two convenient metropolitan area definitions - the urbanized area and the Los Angeles/Long Beach Standard Metropolitan Statistical Area (SMSA), the latter of which corresponds to Los Angeles County. Unlike the other U.S. cities where the urbanized area and SMSA populations correspond reasonably well, there is quite a large difference (2 million people) between the Urbanized area and the SMSA of Los Angeles. Another difficulty is the Los Angeles metropolitan area as defined is not the full functional urban area which comprises a series of other smaller SMSA's and six Counties. Again, the difficulties in compiling the detailed and varied data across so many separate areas would have been prohibitively time consuming and in some instances may have been impossible. Given the scope of the study, the analysis of the data presented in this chapter is for the entire Los Angeles region in Southern California, with particular emphasis on the Los Angeles (LA) County.

Demography

The Los Angeles region has over 15 million residents, covering approximately 38,000 square miles, encompassing six counties (Los Angeles, Orange, Riverside, San Bernardino, Ventura and Imperial) and 188 incorporated cities in Southern California (Figure 3.1). The region is the second largest in the United States behind the New York region and encompasses nearly half the State's (California) population. The Los Angeles Central Business District (CBD) stands out as the most highly developed center, and also forms the nucleus of the regional core - an intensely urbanized area extending from the Los Angeles CBD to the Pacific Ocean, and including ten other major commercial centers.

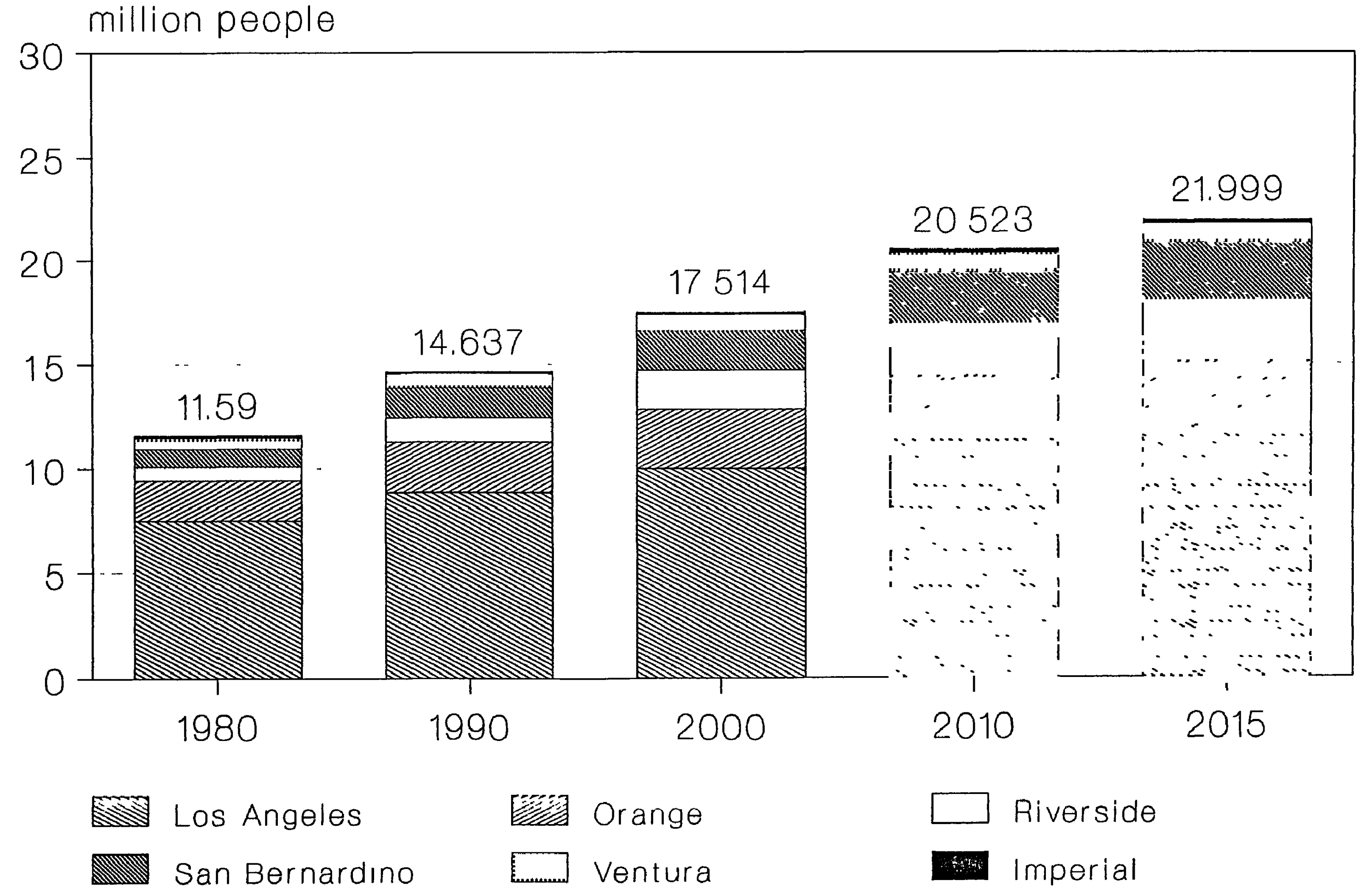
Figure 3 2 shows the growth in population distribution of the six counties located in the Los Angeles region from 1980 to 2015. In 1990 there were 14.6 million inhabitants in the region, 3 million more than in 1980. Half of this increase was due to an influx of migrants, and half to babies born to residents of the region Nearly 60% of the population in the region during 1990 was concentrated in the Los Angeles County (8.86 million) as given in Table 3.1. By 2015, the region is expected to contain 22 million inhabitants with about 54% of its people residing in the Los Angeles County (11.94 million).

Figure 3.1THE LOS ANGELES METROPOLITAN AREA AND SOUTHERN CALIFORNIA



Source Draft Regional Transportation Plan, Summary, SCAG, June 1983

Figure 3.2. Population growth
The SCAG region - Past, Present & Future



Source: SCAG, 1994b.

Table 3.1. Changes in the share of population residing in the Los Angeles County

Year	1960	1970	1980	1990	2000	2010	2015
Percent	77.18	70.03	64.46	60.53	56.81	54.99	54.29

Source: *SCAG, 1994b.*

Regional transport system network

Los Angeles region is well known around the world as an automobile-oriented low density community. Transportation network in the region is a multi-faceted system, comprised of a wide range of transit modes which serve a variety of users The regional streets and highways are comprised of the Interstate Highways, other freeway facilities (mixed-flow and high occupancy vehicle), regionally significant local streets and roads (arterials) and the Transportation System Management (TSM) improvements that are applicable to the roadway system.

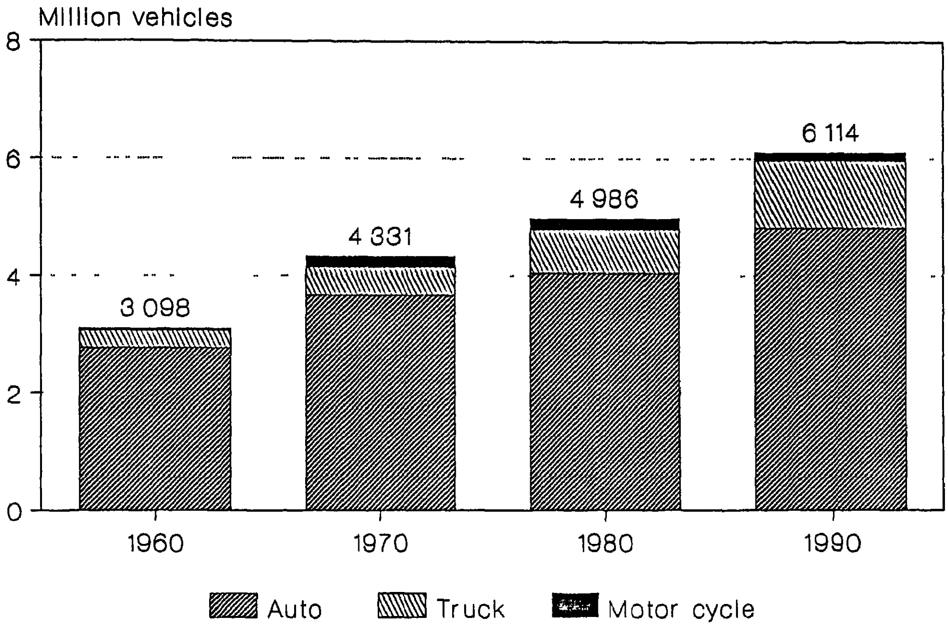
The region contains more than 14,000 miles of arterial highways, including almost 2,000 miles of freeways, and over 44,000 miles of local street (*SCAG, 1994a*) The roadway system is the backbone transportation network, supporting travel primarily by people and providing access to economic markets and goods movement components of the Metropolitan Transportation System (MTS). This vast highway network caters to extensive bus systems as well as trucks and cars Within heavily built-up Los Angeles County, the freeway system constitutes only 1% of the total highway/lane mileage, but carries 55% of the total vehicle-miles of travel (*OECD, 1988*).

The local level roadway system is an integral part of the overall regional transportation network as it serves to allow regional users immediate access to specific locations. The local street and road system serve as a feeder and distribution network for the regional highway system. Typically, the planning, development and maintenance of local streets is the responsibility of individual municipalities and jurisdictions, and hence does not fall within the control of the SCAG (Southern California Association of Governments) plan process. However, it is important to note that the quality local streets has been declining as municipalities struggle to improve and maintain roadways with diminishing fiscal budgets.

Growth of registered vehicles

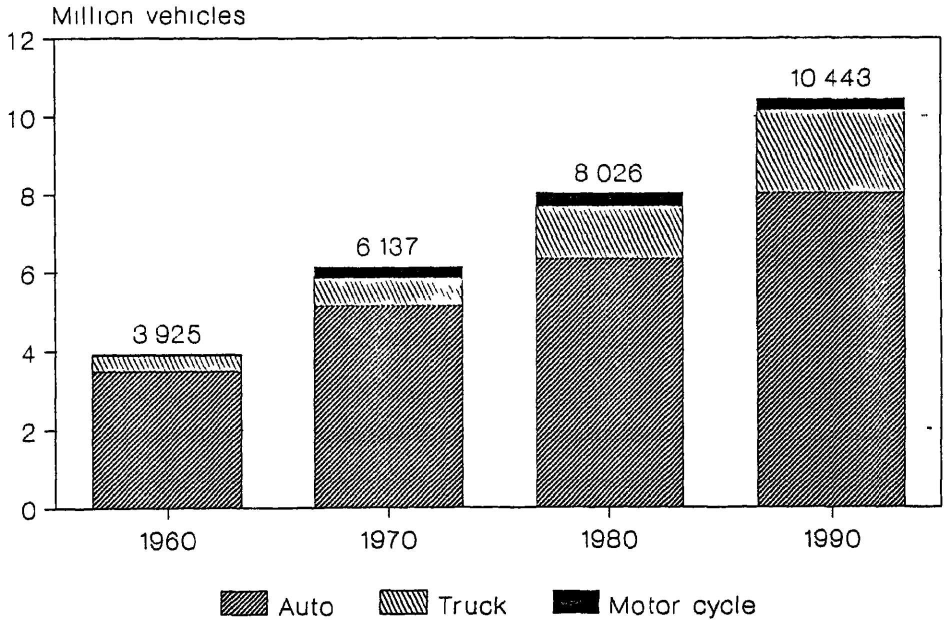
Data on growth of different type of motorized vehicles since 1960 for the six counties were compiled from the Department of Motor Vehicles and presented in Appendix 3.1. The composition and growth of motorized vehicles in Los Angeles County and in the entire region is shown in Figures 3.3 and 3.4 respectively. While the total number of vehicles

Fig.3.3. Vehicle growth and composition Los Angeles



Source California Dept of Trans, 1994

Fig.3.4. Vehicle growth and composition Southern California



Source California Dept of Trans, 1994

registered in the Los Angeles (LA) county increased almost twice over the last four decades (from 3.1 million in 1960 to 6.1 million in 1990), the share of vehicles registered in the LA county with respect to the Southern California region as given in Table 3.2, declined (from 79% in 1960 to 59% in 1990). This suggests that though the registration of motor vehicles in Los Angeles county increased in absolute value, but decreased in real value. During the last decade (1980-90) in the LA county, while the annual registration of passenger car and truck went up by 1.75% and 4.45% annually, that of motor cycle declined by 2.65% (Table 3.2).

Table. 3.2. Percentage of vehicles registered in LA county w.r.t. Southern California

Year	**Auto**	**Truck**	**M-Cycle**	**Total**
Share of vehicles registered in LA county w.r.t the region (%)				
1960	79.44	74.94	73.50	78.93
1970	71.37	66.83	65.58	70.58
1980	63.91	54.95	57.18	62.11
1990	60.05	53.46	54.46	58.55
Annual growth rate of vehicles in LA county (%)				
1960-70	2.85	4.83	20.83	3.41
1970-80	0.99	4.54	0.50	1.42
1980-90	1.75	4.45	-2.65	2.06
Annual growth rate of vehicles in the Southern California region (%)				
1960-70	3.95	6.03	22.22	4.57
1970-80	2.11	6.60	1.89	2.72
1980-90	2.39	4.73	-2.18	2.67

Regional transit (bus and rail) network

Bus

At present, public transportation in the Southern California region is operated directly or under contract by about 17 separate public agencies. Public providers collectively own one of the largest bus transit bus fleets in the world, with the Los Angeles County Metropolitan Transportation Authority operating the third largest bus fleet in the United States.

During 1990, public transportation providers operated approximately 516.5 million unlinked trips in the SCAG region (*SCAG, 1994d*). Transit providers operated more than 125 million revenue miles and about 10 million revenue hours with a morning peak-hour bus fleet of about 2,800 vehicles. About 82% of the total revenue miles and 83% of the total revenue hours were confined to the Los Angeles County alone.

The "intersecting grid" design is presently the dominant route network used in Orange County, the City of Los Angeles, and areas of LA county. The grid network comprises about 235 individual routes operated on north-south and east-west streets and providing extensive area coverage. 98% of the existing regional transit bus service is provided by nine major public providers: The Los Angeles County Metropolitan Transportation Authority (LACMTA); the Orange County Transportation Authority (OCTA); and the Riverside Transit Agency (RTA), OmniTrans, and South Coast Area Transit (SCAT) -- the major regional operators in Riverside, San Bernardino, and Ventura counties, respectively. The municipal operators in Long Beach, Santa Monica, and Foothill Transit and the Los Angeles Department of Transportation provide bus services in Los Angeles county.

Regional public transportation improvements are currently directed toward the implementation of the rail programs designed to create the infrastructure which supports service on high-and-medium-capacity corridors. The proposed improvements include nine urban rail lines, nine commuter rail lines, and two inter-city corridor lines.

Metrolink System (Commuter Rail)

The Metrolink (commuter rail) is operated by the Southern California Regional Rail Authority (SCRAA). Commuter rail service began in 1990 and at present Metrolink Regional Commuter Rail system caters to passenger travel movement between Los Angeles, Moorpark, Santa Clarita, Pomona, Claremont, the Montclair Transit Center, Riverside, San Bernardino, Palmdale, Lancaster, City of Camarillo in Ventura County and Oceanside.

Metrorail System (Urban Rail)

The Metrorail (urban rail) is operated by the LACMTA. The Metro Blue line began service in 1990 and at present it caters to travel demand between the Los Angeles Financial District and Downtown Long Beach in 1990. The first segment of the Metro Red Line began operations between Los Angeles Union Station and Alvarado Street in early 1993. Red Line service to Wilshire/Western is scheduled to commence in 1996, service to Hollywood in 1998 and services to North Hollywood, East-Los Angeles and Mid-City areas by the year 2001. The Green Line is currently under construction as part of the Glen Anderson (I-105) Freeway project.

Congestion

Currently, in the urbanized counties and in many of the transit corridors that link urbanized counties to other parts of the region, congestion continues to be a major problem. Although freeways are generally posted to carry traffic at 55 mph (a national limit imposed after the motor fuel shortages experienced in the 1970s), more than 25% of the regions 14,000 miles of freeways experience a "breakdown" condition (i.e., severe congestion, stop-and-go movement less than 20 mph average speed) during the peak hours and recurrent congestion (i.e., 20-35 mph for more than 6 hours per day) during the off-peak periods. Daily congestion results in 2,152,000 hours of delay added to travel times (*SCAG, 1994c*).

The cost of congestion to any particular person on how many hours of traffic delay he or she experiences and the value of his or her time, is related to income. According to a recent study, the total estimated cost of congestion in the Southern California region to individual motorists was roughly $7.7 billion in 1991 (*Cameron, 1994*). The study reveals that in 1991, congestion cost for an average individual in the highest income group was $1,570 per year. While the corresponding figures for middle and low income group were $320 and $60 respectively. Also, congestion costs represent roughly 4% of income for the highest income group, 3% for the middle income group, and 1% for the lowest income group. Congestion costs are higher for high-income residents both because they spend more time travelling, and hence are exposed to more delays, and because their wage rate is higher. While the average congestion delay in the region was 11 minutes per person each day in 1991, high-income residents experienced an average 18 minutes and low-income residents 5 minutes of delay daily. According to the SCAG, the cost of wasted time, extra fuel and higher insurance premiums stemming from congestion could soon rise to more than $9.4 billion annually (*SCAG, 1988*). Another study indicated that congestion in the region is 42% worse than the average U.S. metropolitan area (*Texas Transportation Institute, 1988*).

Congestion in the region has been increasing during the past two decades due to rapid population growth coupled with declining investments in the transportation system Between 1966 and 1986, California's population increased by 42%. During the same period state transportation spending in real terms decreased by 35% (*Cameron, 1991*). Consequently, congestion is now growing at a rate of 15% to 20% per year in the South Coast Basin (*California Air Resources Board, 1989*).

In addition to the disparity between population growth and transportation investments, demographic shifts have increased demands on the system and have contributed to congestion. Frequently cited shifts include increased suburban development, increased auto ownership per household, increases in the relative share of service sector employment, increases in the number of employed women. Personal vehicles, which on average can carry four or more people, actually carry during peak hours an average of 1.13 persons per car -- a vast underutilization of the rolling-stock resource (*SCAG, 1988*).

To reduce the number of in-use vehicles and yet preserve mobility for those who no longer drive will require the average vehicle to carry more than just the driver -- and not at great inconvenience to the remaining drivers or the new passengers. Because of limitations on additional highway capacity, mobility will not be restored or maintained until vehicle occupancy rates are increased.

Vehicle ownership

Vehicle ownership is expressed as the total number of vehicles registered per 1000 people. Table 3.3 gives the trend in ownership pattern of different vehicles in the LA county.

Table 3.3. Per capita motor vehicle registrations (vehicle/1000 Persons)

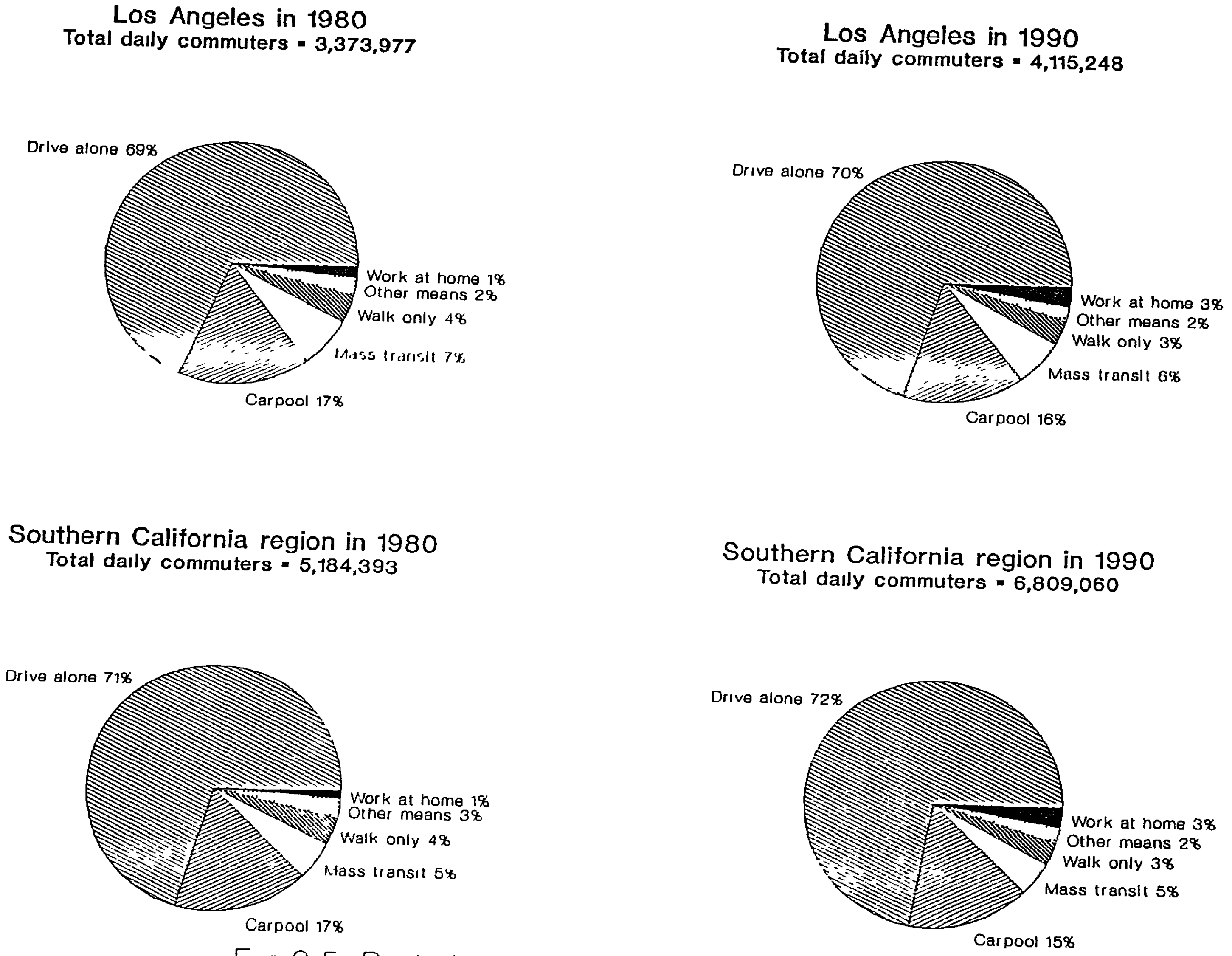
Vehicle type	1960	1970	1980	1990
Passenger car	459	521	541	544
Motor cycle	5	26	26	17
Total (including truck)	513	615	667	690

Since 1960, number of vehicles per inhabitant in Los Angeles have increased and is now probably the highest in the United states. In 1990, for every 1000 people, there were 544 cars, 17 motor cycles and 690 total vehicles (which include trucks).

Travel pattern

Approximately 49 million trips are generated daily (in a typical weekday) throughout the SCAG region. The highest trip generating traffic subregion is the Los Angeles County, generating almost 11.5 million trips daily followed by Orange County, generating over 9 million daily trips (*SCAG, 1994a*). Of the 49 million daily trips, approximately 13 million trips (27%) are estimated to be "to work" or "commute" trips. Commute trips consistently range between 24 and 29% of the total daily trips.

The Southern California's population is a commuter society that relies on Single Occupancy Vehicles (SOV) for a majority of all trips. Figure 3.5 shows the total number of daily commuters for "to work" and their distribution of commuting modes in the Los Angeles and the Southern California region during 1980 and 1990. As can be noted over 70% of the journey to work in the region in 1990 was on SOVs. In Los Angeles County, there has been an increase in share of SOVs between 1980 and 1990. While, the share of commuters who



Los Angeles in 1980
Total daily commuters = 3,373,977

Los Angeles in 1990
Total daily commuters = 4,115,248

Southern California region in 1980
Total daily commuters = 5,184,393

Southern California region in 1990
Total daily commuters = 6,809,060

Fig 3 5 Distribution of commuting modes
Source: 1980 and 1990 Census of Population

depend on car pool and also on mass transit has declined. However, share of commuters who work at home has increased. For home to work commutes, Average Vehicle Ridership (AVR) is 1.38 persons per car (*SCAG, 1994c*).

Excepting the Los Angeles County, in all other counties, more than a total of 50% of the total vehicle miles takes place on either freeways or major arterials. Table 3.4 gives the total vehicle miles travelled daily by different categories of roadways in the region for 1984, 1987 and 1990. While the Vehicle miles travelled has increased between 1984 and 1990 average vehicular speed on different types of roadways have declined. The average speed during the morning peak period is 29.6 mph (*SCAG, 1994c*).

Table 3.4. Vehicle miles traveled and vehicular speed on different roadways

Roadways category	**Daily vehicle miles traveled (in thousand)**			**Average speed (mph)**		
	1984	**1987**	**1990**	**1984**	**1987**	**1990**
Freeway	113109	110538	141856	48	43	44
Major arterial	93018	25541	27526	28	24	25
Primary arterial	-	68224	69377	-	26	25
Secondary arterial	11702	19762	19106	28	26	22
Other	3462	19275	22332	26	40	38
Total	221291	243339	280197	35	33	32

Source: *SCAG, 1994c.*

Only 5.6% of the population in the region use some form of transit to commute to work. The corresponding figure for the Los Angeles county is marginally higher (6 5%). On an average each person makes 3.4 daily trips in their automobile, and each person drives an average of 20.48 miles per day.

Energy consumption trend

Los Angeles region

In 1991, total fuel consumption by the road based vehicles in the Los Angeles region was 6.27 billion gallons (*Cameron, 1994*). However, in 1979, the corresponding value was 6.04 billion gallons as given in Table 3.5 (*SCAG, 1982*). This indicates that the transportation energy consumption in the region went up marginally with an annual average growth rate of 0.34% between 1979 and 1991.

Table 3.5. Transportation energy use by modes* in the LA region during 1979

Transport mode	Gasoline		Diesel
	Consumption (10^6 gallons)	Percentage	
Automobile	4193	74.5	neg.
Light duty truck	799	14.2	-
On-road motorcycle	15	0.3	-
Medium duty truck	145	2.6	-
Heavy duty truck	422	7.5	346
Off-road vehicles	48	0 9	74
Total	5622	100	420

*Does not include buses, airplanes, rail-road.
Source: *SCAG, 1982.*

Automobiles accounted for nearly 75% of the total gasoline use in the Los Angeles region (Table 3.5). As given in Table 3.6, annual consumption of gasoline by automobiles in the region grew by about 1.05% between 1980 and 1990 (from 4.7 billion gallons in 1980 to 5.2 billion gallons in 1990). Of the total gasoline consumed in the Los Angeles region, 73% of the gasoline was consumed in the Los Angeles County, while 11% was consumed in San Bernardino County, 9% in Riverside County, 6% in Ventura County and 1% in Imperial County. The share of gasoline consumption in different Counties has remained constant between 1980 and 1990 (*California Energy Commission, 1995*).

Table 3.6. Gasoline consumption by automobiles in the LA region (million gallons)

Year	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**
Total	4696	4632	4554	4713	4876	4980	5202	5008	5028	5159	5212

Source: *California Energy Commission, 1994.*

Figure 3.6 shows the trend in transportation (road based) energy consumption in the Los Angeles County for 1960, 1970 and 1980. In 1980, total energy consumed for transportation in the county was 3.64 billion gallons - which is about 60% of the total energy consumed in the region. The annual growth of total energy consumption in the LA county was 0.92% between 1970 and 1980. During the same period, while the diesel consumption went up by 4.14%, increase in gasoline consumption increased marginally at the rate of 0.65%. This is largely the result of a massive swing to smaller, more energy-efficient automobiles.

Alternative motor fuels and vehicles

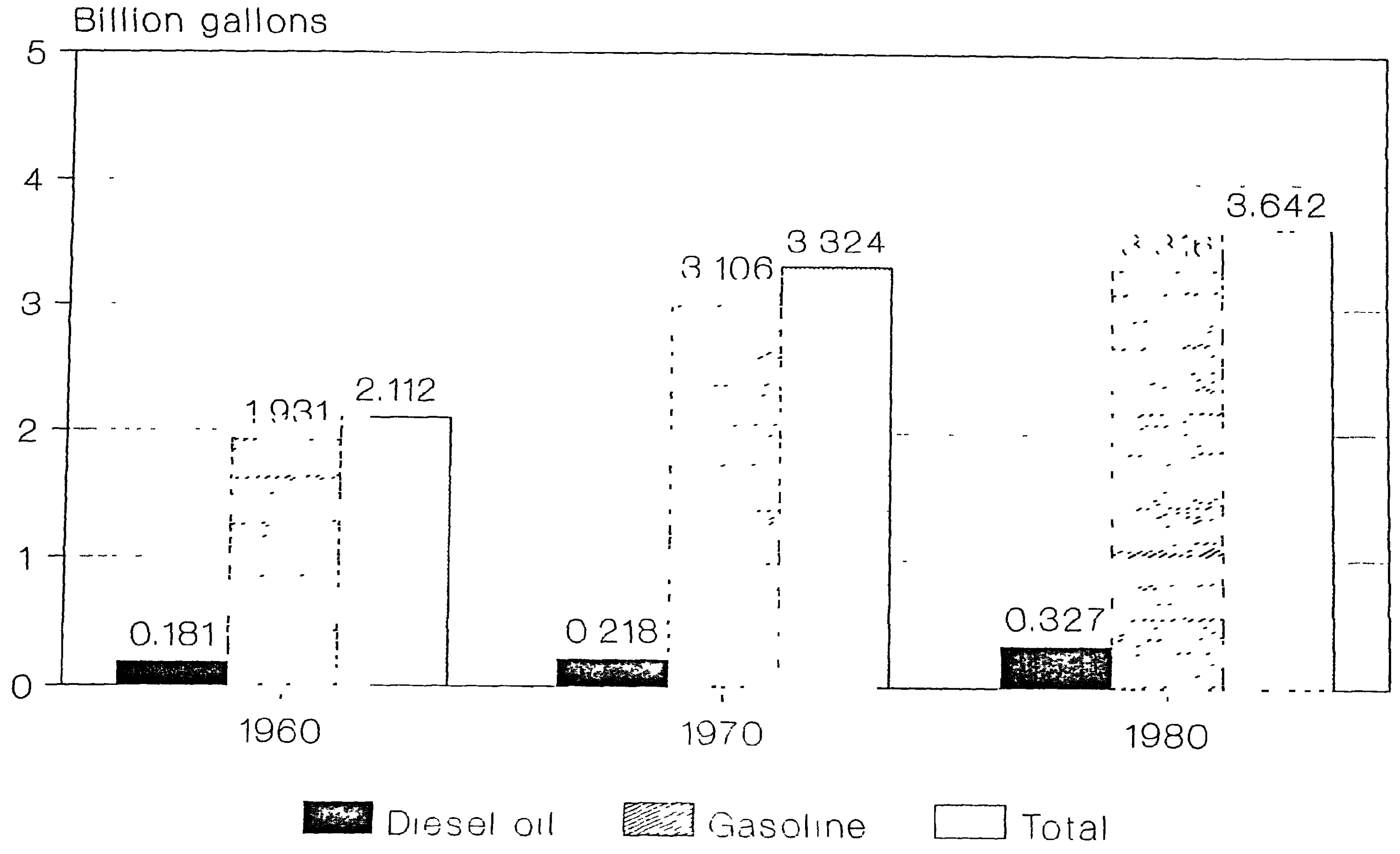
In 1991, 46% of the petroleum consumed in the United States was imported (ORNL, 1994). To reduce the dependence on petroleum fuels, the Alternative Motor Fuels Act (AMFA) was established in 1988, to encourage the use of alternate fuels in the transportation sector. As a result of the AMFA, the Alternative Fuels Data Center (AFDC) was established by the Department of Energy. The AFDC distributes information about alternative fuel vehicles as well as data on refueling sites around the nation.

Since the establishment of AMFA, government and industry have made major efforts to advance knowledge of alternative fuels and alternative fuel vehicles. The U.S. Advanced Battery Consortium (USABC) was established in January 1991 to concentrate efforts on battery development for electric vehicles.

The Energy Policy Act (EPAct) of 1992 included alternative fuel mandates. Purchase requirements were set from 1993 onwards for the federal and state governments, fuel providers (e.g., natural gas and electric utilities), and the private sector.

The alternative fuels route offers prospects in the Los Angeles region, especially in light of new state rules, that by 2003 automobiles sold in California would have to be 70% less polluting than 1993 models (*Bae, 1993*). Further, an impetus has recently been given by the California Air Resources Board's requirement that 2% of all new cars sold in California in 1998 should emit no smog. Alternative fuel vehicles (AFVs) which are capable of operating on any mixture of gasoline and methanol, up to a mixture of 85% methanol (M85); Compressed Natural Gas (CNG) vehicles and Electric vehicles are subject of intense research and development in the United States. CNG based vehicles involve some risks to the attainment of clean air goals because of sizeable NO_x emissions. Both U.S. and Japanese auto makers are racing to introduce a commercially viable electric car, but anticipated high prices and the absence of a ubiquitous network of recharging posts suggest minimal penetration of the private automobile market.

Fig. 3.6. Transportation Energy Use
Los Angeles County



Source: Newman and Kenworthy, 1989

In 1993, the California State had 2,401 CNG vehicles and 10,600 M85 vehicles. More and more of these vehicles are expected to penetrate in the Los Angeles region because of the Clean Air Act.

According to the Southern California Association of Governments (SCAG) transport plan for the Los Angeles region, nearly half of the total sales of vehicles in the region must be ZEVs in 2010 and their share must go up to 60% in 2015, under the California Zero Emission Vehicle (ZEV) program (*SCAG, 1994c*). The USABC consists of the Big Three U.S. auto manufacturers (Chrysler, Ford, General Motors), the Electric Power Research Institute, the electric utility industry, and the U.S. Department of Energy.

The USABC has established research contracts with several companies for development of advanced batteries. Also, a series of Cooperative Research and Development Agreements (CRADAs) with several DOE National Laboratories have been established.

Energy demand forecast in the region

Table 3.7 provides the transportation energy demand forecasts by fuel type in the Los Angeles region for the years 1992, 1995, 2000, 2005 and 2010. These forecasts are estimated by the California Energy Commission.

Table 3.7. Road based transportation energy demand forecast in Los Angeles region

Year	Gasoline (million gallons)	Diesel (million gallons)	M85 (million gallons)	CNG (million therm)	Electricity (million kWh)
1992	5588	821	0	0	16
1995	5575	874	40	8	46
2000	5319	981	375	92	627
2005	5325	1081	525	156	2658
2010	5395	1179	614	189	4239

Source: *California Energy Commission, 1994.*

From 1995, in the Los Angeles region, transport (road-based) sector is likely to consume five types of energy sources. These would include - gasoline, diesel, M85, CNG and electricity. During the next fifteen year period (1985-2010), gasoline demand is expected to go down by 3.22% (from 5.6 billion gallons to 5.4 billion gallons), while demand for all other fuels is likely to increase. Diesel demand is likely to go up by 34% (from 0.9 billion gallons to 1.2 billion gallons); M85 by nearly 15 times (from 40 billion gallons to 614 billion gallons); CNG demand by 23 times (from 8 million therms to 189 million therms) and electricity demand by 90 times (from 46 million kWh to 4239 million kWh) during the same fifteen year period (1995-2010).

Energy demand forecasts given in Table 3.7 are converted into common oil equivalent units to estimate the total energy demand and the share of different types of fuel requirement in the region till 2010 (Table 3.8). Total energy demand in the region is expected to increase marginally from 20 mtoe in 1995 to 23 mtoe in 2010, indicating an annual growth rate of 0.94% (Figure 3.7). The share of gasoline automobiles is likely to decline from nearly 85% in 1985 to 74% in 2010. While during the same period, share of diesel, M85, CNG and electric vehicles will increase in the region. This suggests in the forthcoming years, the Los Angeles region will have more and more penetration of new and alternate clean fuel vehicles. Also, the usage of public transit run on diesel will increase.

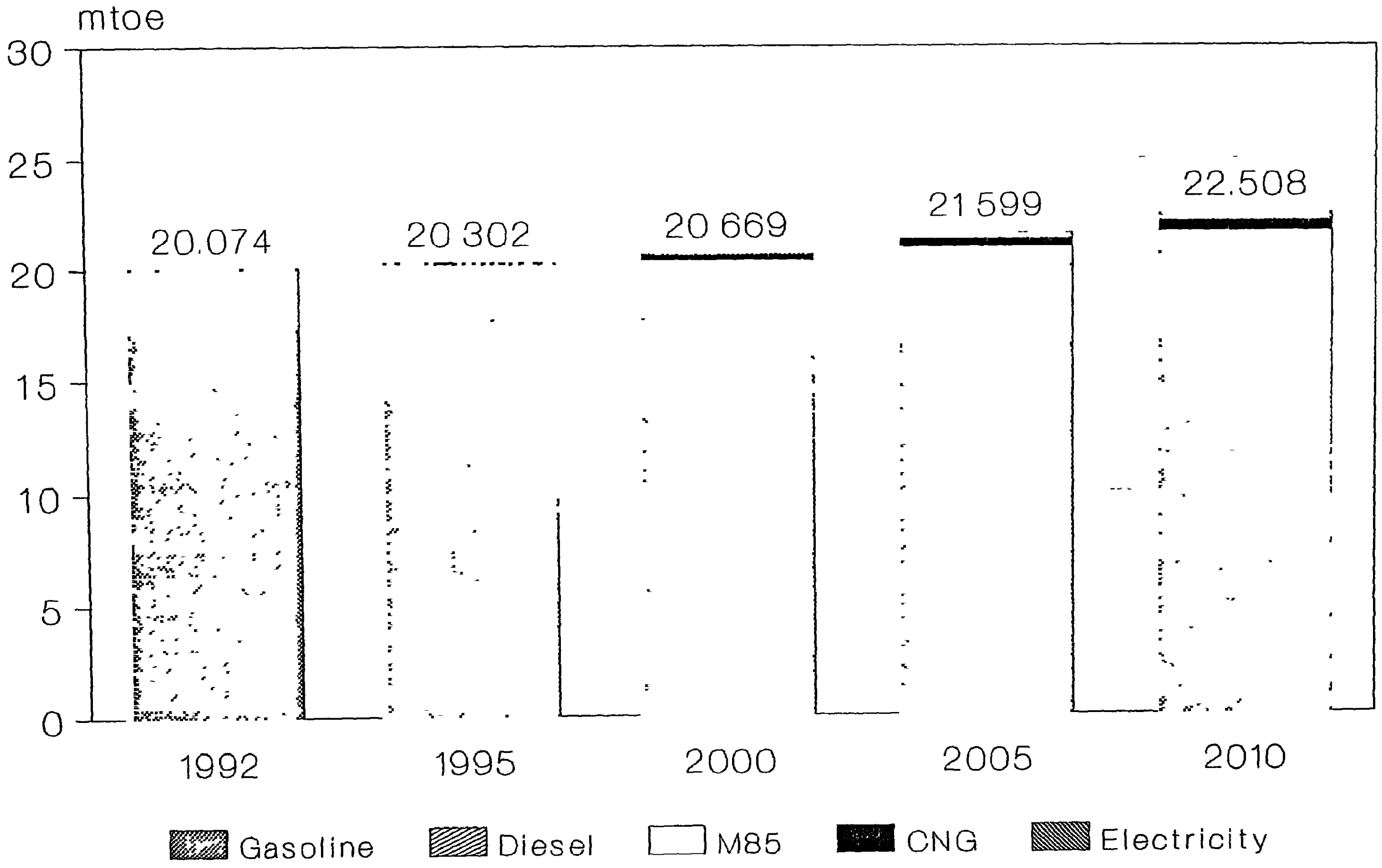
Table 3.8. Total energy demand and share of different fuels in the region

	1992	1995	2000	2005	2010
Total energy demand (mtoe)	20.07	20.30	20.67	21.60	22.51
Share of different fuels (%)					
Gasoline	85.98%	84.82%	79.48%	76.15%	74.03%
Diesel	14.02%	14.75%	16.27%	17.15%	17.95%
M85	-	0.31%	2.90%	3.88%	4.35%
CNG	-	0.10%	1.10%	1.78%	2.07%
Electricity	0.01%	0.02%	0.26%	1.04%	1.59%

Energy efficiency options

The Regional Comprehensive Plan analyzed different options for increasing transport energy efficiency in the SCAG region. These options along with the projected savings in energy that could be achieved by 2010 are presented in Table 3.9.

Fig.3.7. Transportation energy demand forecast in the Los Angeles region



Source: California Energy Comm., 1994.

Table 3.9. Energy efficiency options and savings potential in SCAG region

Options	Savings of gasoline in million gallons
• Implementation of vehicle efficiency standards	5,598
• Develop alternate fuels to improve overall fuel quality	5,882
• Encourage increased vehicle occupancy	4,978
• Encourage telecommuting	5,080
• Encourage development with pedestrian and bicycle emphasis	5,126
• Encourage development with transit and rail emphasis	4,982
• Implement congestion and parking pricing	4,303

Source: *SCAG, 1994a.*

Emissions and air quality in the region

The Los Angeles basin has a mediterranean climate. The surrounding mountains, subsidence inversions, and high solar intensity produce ideal conditions for the atmospheric stagnation conducive to pollutant reaction and buildup. The region's climate and topography are conducive to the formation and transport of ozone (O_3) throughout the region.

Los Angeles suffers the worst air pollution in the United States, and the primary source is automobiles (*UNEP/WHO, 1994*). The most degraded air quality in the region is the populous South Coast Air Basin (SCAB), which includes all of Orange County and the non-desert areas of Los Angeles, Riverside, and San Bernardino Because of both meteorological and commuting patterns within the SCAG region, air quality issues throughout the region are inextricably linked. After nearly fifty years of air pollution control in the region, the intensity of peak pollution levels have diminished but area exposed has increased. Technological gains have been partially offset by population growth and by increases in vehicle miles travelled (VMT).

Contrary to popular belief, air quality is not getting worse in Los Angeles, it is getting better. The most significant automobile emission pollutants in the Los Angeles region are Reactive Organic Gases (ROG), NO_x, and CO. Table 3.10 presents the change in emission of principal pollutants in the region between 1987 and 1990. In 1987, autos accounted for 44% of ROG, 61% NO_x, 88% CO. In the absence of Air Quality Management Plan (AQMP) in the Los Angeles basin, emissions of these pollutants fell after 1979 and will continue to fall through 2010 (by 18.2% for ROG from 1987, by 20.6% for NO_x, and by 45.7% for CO). This reflects the effectiveness of emission controls already in place. This trend is not observed, however, for pollutants little caused by automobiles (5%) like PM_{10} (particulate matter with a diameter of ten micrometers or less). PM_{10} emissions is expected to increase by 46.6%, while SO_2 emissions is likely to decline by only 6.5%, between 1987 and 2010 (Table 3.10).

A substantial proportion of the 2010 projected emissions is the result of population and economic growth. The growth contribution ranged from 23% to 41%, depending on the pollutant (*SCAQMD, 1990*). Thus, assessment of the problem depends very much on the assumptions and projections of future growth. The AQMP assumes that between 1987 and 2010 population will grow by 31%, employment will increase by 36%, and VMT will increase by 62%.

Cars and other motor vehicles are the primary source of the city's infamous smog - primarily ozone (O_3) formed by the photochemical reaction of two motor vehicle exhaust emissions: oxides of Nitrogen (NO_x) and Volatile Organic Compounds (VOCs). In 1990, the maximum hourly O_3 concentration was 660 $\mu g/m^3$. At one site, the federal standard (235 $\mu g/m^3$ not to be exceeded more than once in a year) was exceeded on 103 days. The state standard (180 $\mu g/m^3$ not to be exceeded more than once in a year) was exceeded at all monitoring stations in 1990 (*SCAG, 1991*). Because O_3 is a secondary pollutant, it can only be reduced by controlling its precursors: NO_x and VOCs. Thus, increasingly strict emissions controls have been enforced on NO_x and hydrocarbons. In the past, emissions of VOCs and NO_x have been controlled in the basin by strict industrial and motor vehicle standards set primarily to control O_3. Currently, the South Coast Air Quality Management District's (SCAQMD's) plan for organic compounds and NO_x is designed to meet the California and federal air quality standards for O_3 by 2010.

As far as the other pollutants are concerned, CO was a problem at five out of twenty-five stations in 1991. During the same year, PM_{10} samples exceeded the standard at seven out of eighteen stations, and the region was in compliance with SO_x and lead standards everywhere. Of course, the Clean Air Act requires 100% compliance, but it would be misleading to think that all of Los Angeles is severely polluted for all pollutants all the time.

In the absence of AQMP, the region would fail to comply with federal standards (Bae, 1993). Current NO_x emissions are only a little higher than the federal standard (for NO_2 the federal standard is 100 $\mu g/m^3$, yearly average) and would be at the standard by 2010; the region would remain in compliance with respect to SO_x (for SO_2 the federal standard is 365 $\mu g/m^3$, daily average). O_3 remains the major problem with maximum concentrations about 2.7 times the federal standard and with little improvement by 2010. CO, now more than double the federal standard (10 milligrams/m^3, 8 hourly average) improves through to 2010,

Table 3.10. **Baseline emissions and emissions under AQMP, total and mobile on-road vehicles, 1987 and 2010 (tons/day)**

	ROG	NO_x	SO_x	CO	PM_{10}
A. Total emissions, 1987	1379	1098	124	4972	1072
B. Mobile on-road emissions, 1987	605	664	32	4363	53
Emissions share by on-road vehicles (B/A)	43.9%	60.5%	25.8%	87.8%	4.9%
Baseline emissions, 2010					
C. Total emissions, 2010	1128	872	116	2698	1572
D. Mobile on-road vehicle emissions, 2010	296	494	29	1831	56
Emissions share by on-road vehicles, 2010 (D/C)	26.2%	56.7%	25.0%	67.9%	3.6%
Change in total emissions, 1987-2010 ((C-A)/A)	-18.2%	-20.6%	-6.5%	-45.7%	46.6%
Change in mobile on-road emissions, 1987-2010 ((D-B)/B)	-51.1%	-25.6%	-9.4%	-58.0%	5.7%
Emissions with AQMP, 2010					
E. Total emissions, 2010	178	335	36	1301	854
F. Total emissions reductions w r.t baseline emissions, 2010 (E-C)	950	537	80	1397	718
Change in total emissions w.r t baseline emissions, 2010 ((E-C)/C)	-84.2%	-61.6%	-69.0%	-51.8%	-45.7%
G. Total emissions from mobile on-road vehicles, 2010	219	287	10	1083	18
Change in emissions w.r.t baseline emissions, 2010 ((G-D)/D)	-26 0%	-41.9%	-65.5%	-40.9%	-67.9%

Source: *Bae, 1993.*

particularly with the adoption of stricter California Air Resources Board regulations in June1990. The PM_{10} situation actually deteriorates from 1.8 times the federal standard (50 $\mu g/m^3$, daily average) now to 2.7 times the standard, but it is not affected much by transportation, except indirectly through road construction. These considerations suggest that there is a need for AQMP if the region is ever going to comply with federal standards.

In order to assess the reduction potential of major pollutants, Table 3.10 also gives the projected emissions in presence of AQMP. As can be noted from Table 3.10, if fully implemented, AQMP would bring about a dramatic reduction in emissions, ranging from 46% to 84%.

Regulatory agencies

Air quality control in California is governed by the federal Clean Air Act of 1990 and by the California Health and Safety Code. The U.S. Environmental Protection Agency (EPA) oversees implementation of the federal Clean Air Act. The California Air Resources Board (ARB), a department of the California Environmental Protection Agency, oversees air quality planning and control throughout California and regulates directly-emitted mobile source pollutants and fuel content. ARB divided the state into air basins, based upon meteorological and geographic conditions and, to the extent feasible, political boundary lines. There are three air basins within the six SCAG counties, two of which extend outside the SCAG region.

There are four air quality districts in the SCAG region: (1) the South Coast Air Quality Management District (SCAQMD), covering all of Orange, Riverside and Los Angeles counties and the non-desert area of San Bernardino and Riverside Counties; (2) the Ventura County Air Pollution Control District (VCAPCD), covering all of Ventura County; (3) the Mojave Desert Air Quality Management District (MDAQMD), covering the desert area of San Bernardino County, the portion of Riverside County adjacent to the Colorado River; and (4) the Imperial County Air pollution Control District (ICAPCD), covering all of Imperial County.

All these districts are responsible for stationary source control, air monitoring, and preparation attainment plans and submit to ARB for approval. Except for the Imperial County, all have authority to exercise control over indirect sources, which are facilities that attract large number of motor vehicles.

Ambient air standards

The ARB and the federal EPA have set state and federal ambient air standards for ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), fine particulate matter (PM_{10}), and lead.

Pollutants of major concern throughout the SCAG region are O_3, a colorless toxic gas that irritates the lungs and damages materials and vegetation, and PM_{10} that penetrates and irritates the lungs, alone in combination with gaseous pollutants.

Carbon dioxide from vehicles

For every gallon of oil consumed by a motor vehicle, about 19 pounds of CO_2 (containing about 5.3 pounds of carbon) go directly into the atmosphere (*Walsh, 1993*). During 1991, the total consumption of oil by motor vehicles in the SCAG region was 6.27 billion gallons. This would mean nearly 15.07 million tonne ($6.27 \times 10^9 \times 5.3$ pounds or $6.27 \times 10^9 \times 5.3 \times 0.4536$ kilogram) of carbon emissions from "on-road" mobile sources in the region during 1991.

Table 3.11 gives the estimated emissions of CO_2 (in C equivalent) from road based vehicles for 1992, 1995, 2000, 2005 and 2010. Total emissions of CO_2 will increase by 15% between 1992 and 2010 - indicating an annual rate of increase by 0.78%.

Table 3.11. Estimated CO_2 emissions in the LA region from road based vehicles

Year	Petroleum demand for transportation* (million gallons)	Total CO_2 emissions (million tonnes)
1992	6409	15.41
1995	6497	15.62
2000	6767	16 27
2005	7087	17.04
2010	7377	17.73

Source: **California Energy Commission, 1994.*

Transportation policies and strategies

The Regional Mobility Element (RME) established regional transportation policy for the six-county region of the SCAG. The RME strategy is built on the 20-year (1995-2015) local plans for each county. These plans include existing levels of bus service plus identified rail projects, as well as transit, aviation, truck, and ports capital projects for which funding can be expected through 2015.

The RME anticipates that the following strategies will successfully maintain the regional transportation system - movement of goods and people - efficiently and ensure economic viability of the region while also improve air quality through reduced emissions *(SCAG, 1994c)*.

Transportation demand management

Between 1995 and 2015, as population is likely to grow at just less than 2% per year in the region, daily vehicle trips will increase at less than 1.6%. At the same time, vehicle miles travelled will grow just over 2% each year. The TDM (Transportation Demand Management) strategy attempts to modify people's travel behavior, especially for the future when the impact of population growth on transportation facilities will be significant.

In 2015, congestion on the streets and highways will increase. People will make fewer automobile trips, but the total number of automobile trips made by the increased number of motorists will be 43% more than the trips made in 1990.

Major TDM emphasis has been on reducing the single occupancy vehicles (SOVs) for home-to-work commute (from 72.5% in 1990 to 56.9% in 2015). During this 20 year plan period other changes in the shift from SOVs will include: the promotion and support of ridesharing (from 18% to 18.5%), telecommuting (from 2% to 6.3%), teleconferencing, the use of bus and rail transit (from 5.4% to 13.3%), job site flexible time, alternative work weeks, non-motorized travel (from 2.5% to 3.5%), carpool subsidies, indirect market incentives, and land-use strategies. Over the long term, however, a more market-oriented, user based approach to demand management is proposed. Market incentives have the potential to not only reduce demand but also reduce air quality emissions, while helping provide transportation alternatives and long-term transportation financing.

These TDM strategies complement the region's facilities with investment in high occupancy vehicle, transit and advanced technologies.

But even with TDM measures, and technology improvements, the average daily speed for all trips will decrease from 32.5 mph in 1990 to 27.2 mph in 2015. The delay for drivers on the road will worsen by 106% in morning peak trips and by 196% in daily trips.

Transportation system management

The TSM (Transportation System Management) projects include: traffic signal synchronization and operation components improvements such as closed circuit television, ramp meter installations, traffic operations centers, and the Smart Streets operation in certain cities and counties in the region.

Urban form

The RME has integrated urban form as a mobility strategy, taken into consideration the relationship between land use and travel behavior. The Plan, based on subregional recommendations, promotes land-use development patterns, including job-housing balance, to enhance the efficiency of the region's transportation system. A few subregions already have explicit policies that encourage job-housing balance, balance communities, and transit-oriented development.

Advanced transportation technology

Advanced Transportation technologies are intended to provide consumers with products and services that preserve the same quality of life and convenience of mobility they experience today. These measures are expected to achieve the greatest emission reductions through an aggressive program implemented to achieve moderate to high levels of market penetration. As stated in the RME plan, without support from Advanced Technologies and other high efficient efforts, the current local plans involving traditional transportation improvements cannot meet air quality and mobility mandates.

The Advanced Transportation Technologies employed in the plan includes the use of - (a) zero-emission vehicles, (b) alternate fuels, (c) telecommunications, (d) IVHS and (e) Smart Shuttle transit.

(a) Zero emission vehicles

The technology for zero-emission vehicles (ZEVs) is intended to reduce emissions by accelerating the introduction of these vehicles beyond requirements of government mandates. These would be facilitated through a cooperative public-private partnership project acting as a support program.

By 2010, the annual new vehicle market penetration for ZEVs is expected to reach 50%, involving in excess of 500,000 vehicles and 60% ZEV sales in 2015 About 73,000 jobs are estimated to be created from the start of ZEVs industry.

Accelerating the introduction of ZEVs will reduce the permissible fleet average emissions for light/heavy duty vehicles beyond currently required reductions.

(b) Alternative fuels

Alternative fuel technology aims to increase the rate of emission reductions by accelerating the introduction of low emission, alternative fueled vehicles through cooperative public-private partnerships and the use of market incentives. ARCO, for example, has developed a reconstituted gasoline that, for the first time, reduces the emissions of all automobile pollutants. However, because it raises fuel costs by 16% per gallon, the company was delaying its introduction until further tightening of emission controls provides some incentive (Bae, 1993). Recently, reformulated gasoline developed by ARCO, is being implemented in nonattainment areas such as LA County. Another attractive possibility is the development of prewarmed catalytic converters to deal with the problem that 64% of the hydrocarbon emissions from a 5 mile trip (39% from a 25 mile trip) are produced because of a cold start (*California Air Resources Board, 1989*).

By 2015, annual new vehicle market penetration for alternative fuel vehicles is expected to include 250,000 vehicles for an estimated market share of 14 to 34%. Nearly 9,000 jobs are expected to be created due to the introduction of alternative fuel vehicles.

(c) Telecommunications

The telecommunications technologies involve a number of technologies, including: teleconferencing, tele-services, tele-education, tele-medicine, tele-shopping, tele-banking, telecommuting, and other applications.

Telecommuting as a substitute for home-to-work vehicle trips would be accelerated through cooperative public-private industry clusters.

In 1990, telecommuting impact amounted to a reduction of 4.1% home-to-work trips. This reduction is expected to increase to 6.3% by the year 2015. Total penetration of the market is anticipated to be between 5 and 14% of all work trips. It is estimated that the potential job creation from the sale of all telecommunications technologies is about 42,000 jobs in 2000 and 65,000 in 2010.

(d) Intelligent vehicle highway system

The Intelligent Vehicle Highway System (IVHS) technology represent a variety of technologies that basically transfer information to the driver of the vehicle to improve the safer and more efficient use of the highway system. Thus, IVHS technologies or products have two major deployment applications: highway-road systems and on-vehicle.

By 2015, the market penetration of IVHS technology is expected to exceed 250,000 vehicle information device units. IVHS technologies are intended to reduce mobile source emissions from light and heavy duty vehicles through improved operational performance of the transportation system.

IVHS technologies include: (1) Advanced Traffic Management System (ATMS) technologies like computerized signal and control systems that synchronize lights to reduce unnecessary stops, thus improving the vehicle emissions driving cycle; (2) Advanced Traveler Information System (ATIS) technologies that warn drivers in advance of severe congestion; (3) Advanced Vehicle Control System (AVCS) technologies such as collision-avoidance systems that reduce accident related congestion; (4) Commercial Vehicle Operation (CVO) systems that control the routing of commercial fleet vehicles to avoid excess travel and congestion; and Advanced Passenger Transportation System (APTS) technologies that can dispatch Advanced Shuttles more efficiently or give the time and location of the next bus or train to the transit passenger.

IVHS technologies would be deployed by establishing a private/public cluster to develop a market plan for the consumer. IVHS technologies is expected to provide 61,000 new jobs by 2000 and over 140,000 new jobs by 2010.

(e) Smart Shuttle transit

Smart shuttles are demand responsive transit modes, using advanced transportation technologies to provide service more tailored to the needs of individual riders The goal for smart shuttles is to develop, implement, and integrate a public-private transportation service that offers an attractive alternative to the gasoline-powered automobile in applications that defy conventional transit (*Bruun and Morlok, 1995*). Implementation of smart shuttles would be accomplished through the creation of public-private partnership with the mandate to create a market environment which promotes development and use of alternative public transportation services along with integration of new technologies and removal of regulatory barriers. By 2015, smart shuttles and conventional transit with TDM programs are expected to account for 10 to 14% of all work trips and involve 50,000 smart shuttle vehicles in the region In terms of jobs, smart shuttle industry is expected to provide 65,000 new jobs by 2010 (*SCAG, 1994c*).

All the above listed RME strategies is likely to improve Air Quality, particularly that of CO, NO_x and ROG significantly in each of the regional air basins.

Implementation strategy

During 1994, the RME proposed a Southern California Economic Partnership (SCEP), which is a public-private sector collaborative effort that will bring government and industry together to determine how best to successfully deploy new technologies into the Southern California market place.

Market incentive implementation, including refinement, pricing levels, and a legislative agenda, will be undertaken by a committee charged with these responsibilities and appointed by the SCAG Regional Council. The Committee will also be charged with the task of reviewing and making recommendations on these issues related to innovative funding.

Emission reductions potential with TDM measures

In 2010, the transportation emissions reductions expected from Air Quality Management Plan (AQMP) range from 3.8% for PM_{10} to 97.4% for CO (Table 3.12).

Table 3.12. Emission reductions, 1987-2010, contribution of transportation measures

tons/day

	ROG	NO$_x$	SO$_x$	CO	PM$_{10}$
Total baseline emissions, 2010 (A)	1,128	872	116	2,698	1,572
Emissions with AQMP, 2010 (B)	178	335	36	1,301	854
Total emissions reductions (C)	950	537	80	1,397	718
Transportation emissions reductions (D)	284	413	50	1,360	27
Transportation share (D/C)	29.9%	76.9%	62.5%	97.4%	3.8%
VMT/VHT emissions reductions (E)	103	136	12	629	16
VMT/VHT share of transportation (E/D)	36.3%	32.9%	24.0%	46.3%	59.3%
VMT/VHT share of total emission reductions (E/C)	10.8%	25.3%	15.0%	45.0%	2.2%
(a) Alternate work schedules	21.1	19.7	1.7	134.2	2.8
	2.2%	3.7%	2.1%	9.6%	0.4%
(b) Modal shift strategies	9.0	10.7	0.9	59.5	1.5
	0.9%	2.0%	1.1%	4.3%	0.2%
(c) Growth management	44.0	30.5	2.7	272.6	4.6
	4.6%	5.7%	3.4%	19.5%	0.6%
(d) Freeway capacity enhancement	17.3	14.1	0.8	105.0	1.4
	1.8%	2.6%	1.0%	7.5%	0.2%
(e) Others	11.6	61.0	5.9	57.7	5.7
	1.2%	11.4%	7.4%	4.1%	0.8%

Source: *SCAQMD, 1990.*

Emissions reduction from on-road vehicles can be reduced either through technological solutions or by cutting total vehicle miles travel (VMT) and total vehicle hours travel (VHT). The latter method is primarily concerned with the automobile emissions that can be attacked by transportation and land use planning measures. Such measures include increasing transit availability and ridership (modal shift), promoting ridesharing (carpools and vanpools), facilitating alternative work schedules, and more complex interventions to shorten work trips by promoting "jobs-housing" balance, freeway capacity enhancement and a residual "others" category.

One of the studies examined the contribution made by transportation and land use measures to achieve the air pollution emission targets of the 1991 Air Quality Management Plan in the Los Angeles Basin (*Bae, 1993*). The study reveals that the measures aimed at reducing vehicle miles traveled (VMT) have only a modest impact on reducing air pollution. Technological solutions to the automobile emissions problem are much more important.

VMT/VHT reduction measures and its impact on air quality

The VMT reductions are unlikely to be achieved in the short run because they conflict with the determinants of travel behavior. The basic question is, can the air quality goals of AQMP still be attained? The answer requires calculating (1) the emission reductions for each of the VMT/VHT reduction measures; (2) the VMT/VHT reduction share of total transportation emission reductions in AQMP; and (3) the transportation share in total AQMP emission reductions.

Transportation measures are critical to AQMP emission reduction targets, as they are responsible for almost all CO reductions and more than three-quarters of NO_x reductions (Table 3.12). They are less important for ROG and SO_x, and trivial for PM_{10}. However, the emission reductions derived from VMT/VHT measures show that they account for only 33 to 46% of the transportation emission reductions for critical pollutants - CO and NO_x. In other words, technological measures to reduce automobile emissions and transportation measures for vehicles other than autos are much more important than transportation measures aimed at reducing VMT/VHT, accounting for up to two-thirds of emission reductions.

Table 3.12 also provides the contribution of VMT/VHT reduction measures to AQMP emission reduction targets. The PM_{10} contribution (2%) is minimal, the ROG share is 11%, while the shares of NO_x, SO_x and CO are 25%, 15% and 45% respectively. The last five rows of Table 3 12 show the proportions of total AQMP emission reductions that rely on each type of VMT/VHT reduction strategy. Of the three critical pollutants (ROG, NO_x and CO) and the two strategies requiring the most adjustment in travel behavior, alternative work schedules account for 2.2, 3.7, and 9.6% of AQMP reductions, while modal shift strategies account for only 0.9, 2.0 and 4.3%. These two strategies in the recent past, which have received so much attention in the media and among planners and have generated the most hostility, turn out to be marginal to the attempts to make Los Angeles comply with federal clean air standards.

As can be noted from Table 3.12, growth management has the biggest impact on emission reductions, accounting for around two-fifths of VMT-related emission reductions.

Chapter 4. Delhi

Demography

Delhi, a very ancient and historic city of India, has witnessed phenomenal population growth during the past few decades. From a population of 0.4 million in 1901, its population has grown to 9.4 million in 1991 (Figure 4.1). There was a sudden rise in the population in 1947, as a result of partition. Since 1951, the population of Delhi has been increasing at a rate of 52-53% every decade During the 1981-91 decade, its population grew by 3.2 million. Taking this figure, on an average, 877 persons were added to Delhi's population everyday in the 1981-91 decade. If this growth rate continues in the present decade (1991-2001), then Delhi will have 14.1 million people by the year 2001.

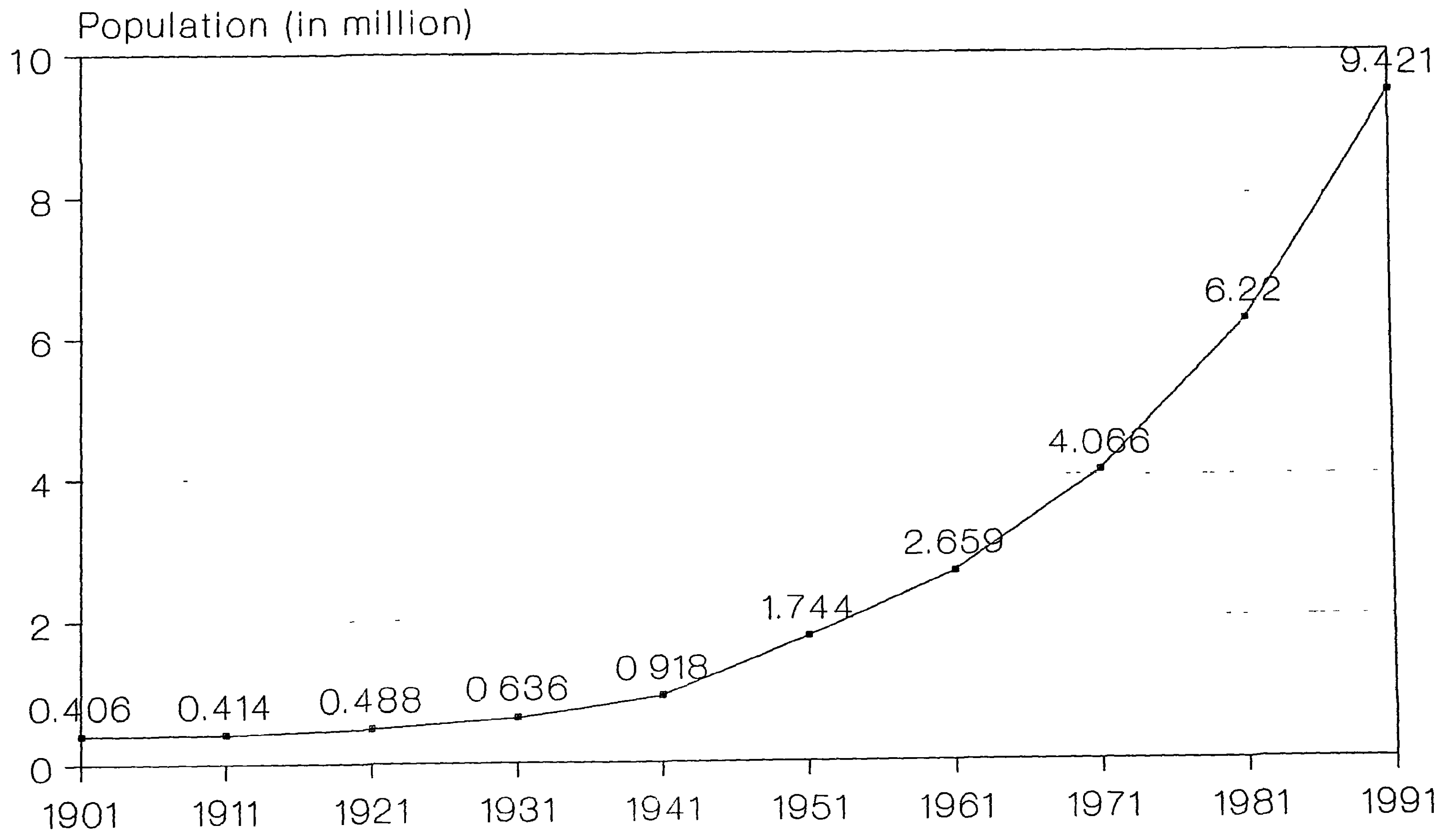
Urban population constitutes a major portion of total population in the National Capital Territory of Delhi. In 1981, the share of urban population was 92.73% of the total population, but fell to 89.93% in 1991. The annual growth rate of urban population of Delhi was 5.82% during 1971-81, while during 1981-91, the corresponding growth rate declined to 4.69% The average population density of urban Delhi was 14,313 persons per sq.km. in 1991.

Figure 4.2 presents the map of National Capital Territory of Delhi (in short Delhi). Up to 1971, only Delhi Municipal Corporation (DMC) (urban), New Delhi Municipal Committee (NDMC), and the Delhi Cantonment Board constituted urban Delhi In 1981, 27 new census towns were added which increased the area to 591.85 sq km. from 446.26 sq km The population of DMC (urban) has doubled between 1971 and 1991. Against this, in the NDMC area, the populations in 1981 and 1991 were less than that in 1971. The population in the Delhi Cantonment Board is less than that of NDMC. Both NDMC and Delhi Cantonment Board have about 43 sq.km. of area, but the population of cantonment is only one-third of NDMC's population in 1991 The population density has increased considerably in DMC (urban) over the last two decades, recording a density of 19,899 persons per sq.km. in 1991, as compared to 9,119 persons per sq.km. in 1971.

The Delhi Development Authority (DDA) has divided the entire National Capital Territory into 15 divisions. Out of these, 8 divisions form the urban area with a total area of 525.74 sq.km., and the population density in 1981, ranging between 53,685 and 6,876 persons per sq.km. (*Master Plan of Delhi: 1981-2001, 1990*).

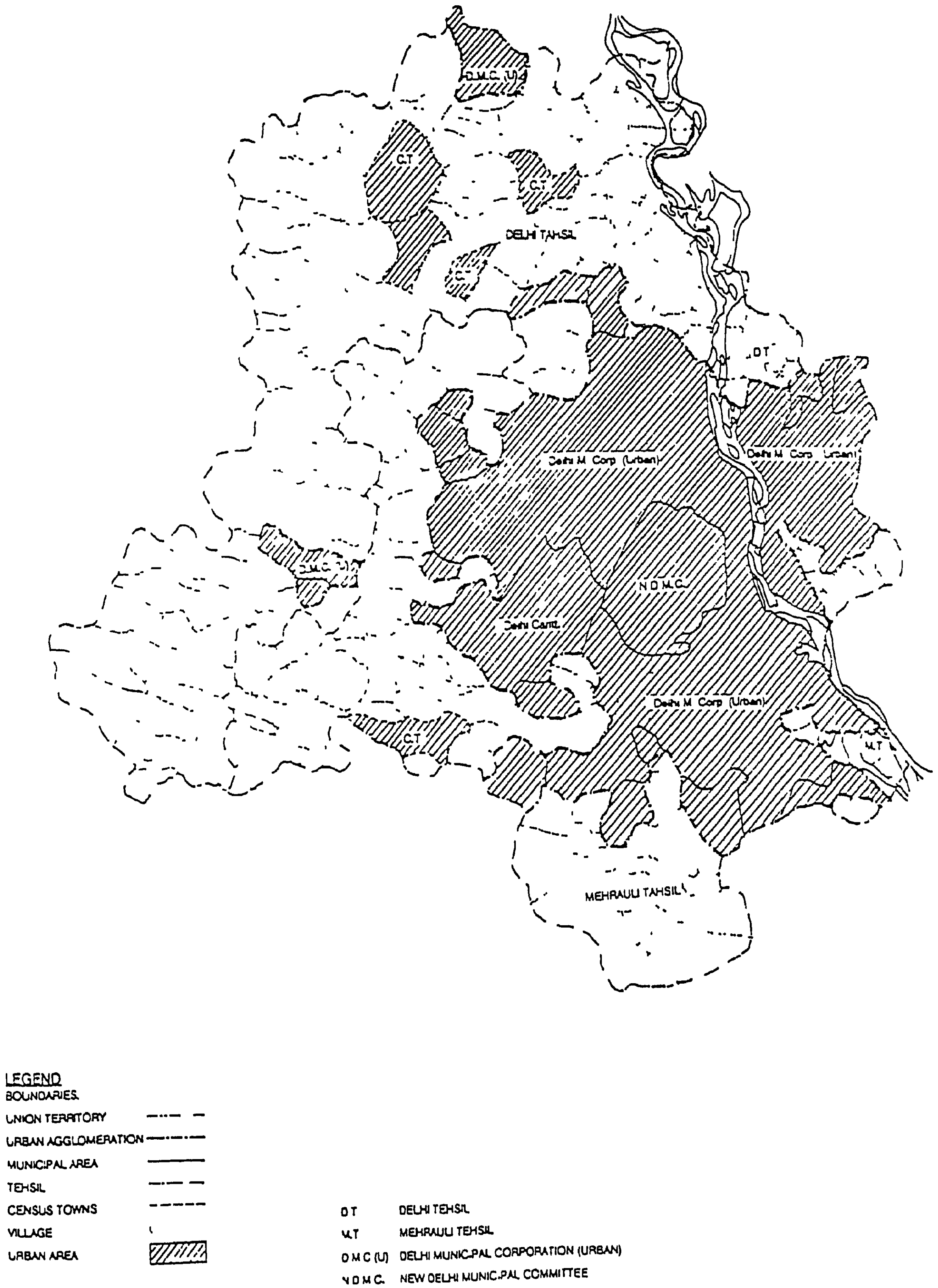
To control the rapid growth of population in the National Capital Territory of Delhi, the National Capital Region (NCR) was formed in 1986, with the idea of diverting the population, housing and economic activities to satellite towns. The NCR is spread over

Fig.4.1. Population growth in Delhi



Source: Census of India, 1991

Figure 4.2. The Delhi Metropolitan Area



30,242 sq.km. covers parts of the states of Haryana, Uttar Pradesh and Rajasthan, besides the National Capital Territory of Delhi.

For the purposes of planning, the NCR Planning Board formed the Delhi Metropolitan Area (DMA), comprising of the National Capital Territory of Delhi, Ghaziabad-Loni Complex and NOIDA in U.P., Faridabad-Ballabhgarh Complex, Gurgaon, Bahadurgarh and Kundli in Haryana. The DMA which is spread over an area of 3182 sq.km. is expected to contain the population of National Capital Territory of Delhi with a total assigned population of 11.2 million by the year 2001 (Table 4.1).

Table 4.1. Population Assignment for 2001

Regional description	**Area (sq.km.)**	**Population in 2001 (million)**		
		Urban	**Rural**	**Total**
National Capital Region	30242	23.4	9.1	32.5
Delhi Metropolitan Area	3182	14.7	0.3	15.0
National Capital Territory of Delhi	1483	11.0	0.2	11.2

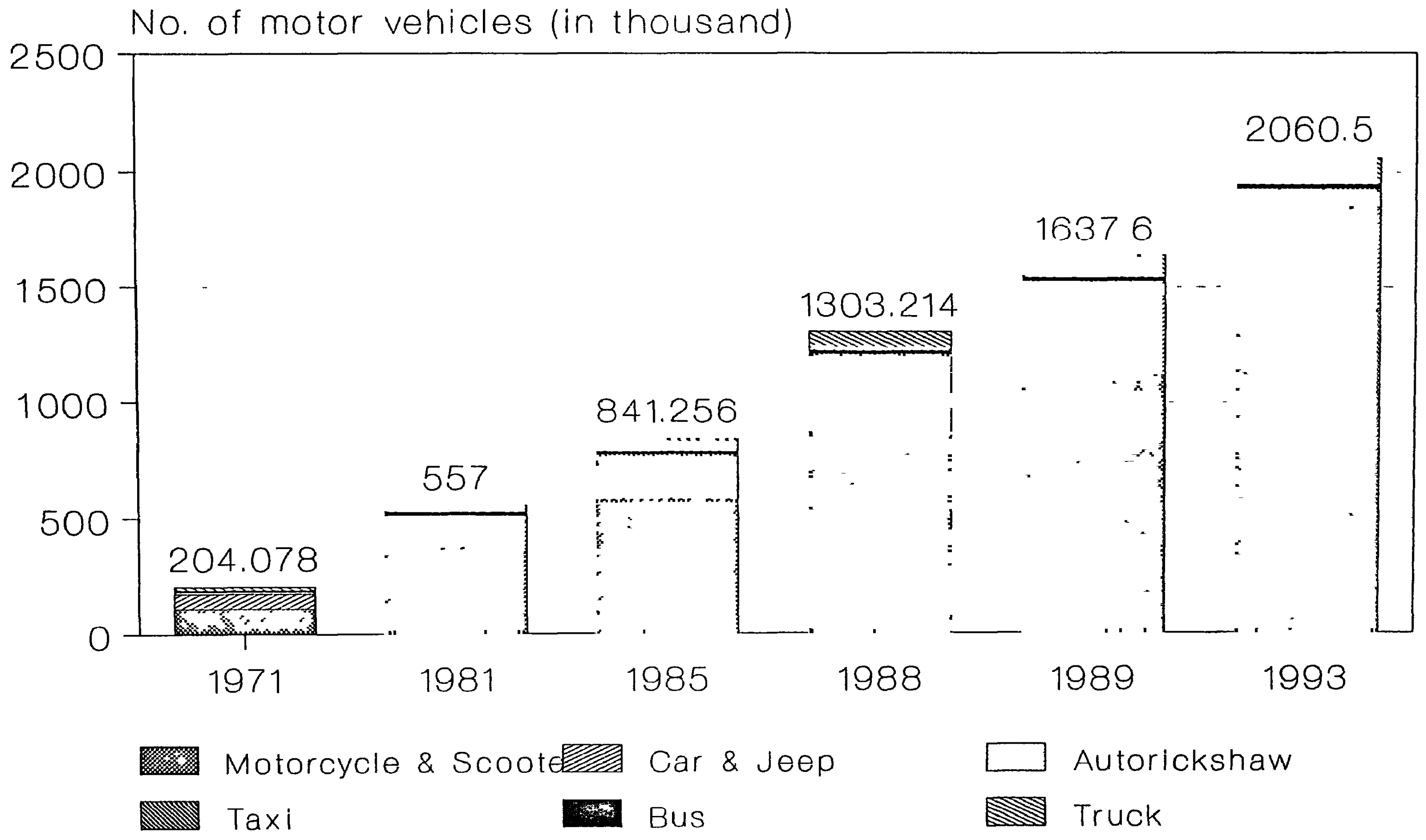
Source: *National Capital Region Planning Board*

Transportation system network and growth trends

The city of Delhi has been experiencing an exponential growth in motorized vehicles - with an average growth rate of 18.12% per annum between 1985 and 1989 (Figure 4.3). The growth of vehicles in Delhi has been faster than the population. Its urban population which was 3.65 million in 1971 increased to 5.73 million in 1981 and 8.47 million in 1991 indicating a more than two folds increase in the last two decades. While the corresponding figures of the increase in vehicle population accounts for 0.21 million, 0.57 million and 2 million respectively, which indicates more than nine times increase in the last two decades.

Delhi also has the largest motorized vehicle population of over 2 million even though it ranks third in the list of megacities of the country after Bombay with 0.65 million vehicles and Calcutta 0.48 million vehicles and Madras, the fourth megacity has only 0.63 million vehicles. It is interesting to note that the vehicle population of all the remaining three megacities taken together accounts for 1.76 million vehicles which is even less the vehicle population of Delhi alone during 1990. Perhaps this is due to the fact that Bombay and Calcutta have suburban rail services unlike Delhi.

Fig.4.3. Vehicle growth and composition
Delhi



Source: ACMA, 1993 and NIUA, 1994.

There has been a sharp change in vehicle composition in Delhi in the last two decades (Figure 4.3 and Table 4.2). The two wheelers (i.e., motorcycle and scooter) have become the most popular mode of personal transport and their number is rising further. Of the total vehicles in 1971, nearly 53% were two wheelers, and this rose to 68% in 1993. The corresponding figures for car and jeep were 30% and 22% respectively. The change in vehicle mix was more gradual between 1988 and 1993. Among the public transport vehicles, there are over 20,000 buses, 70,000 autorickshaws (or three-wheelers), and 10,500 taxis. In addition to these passenger vehicles, Delhi has about 0 11 million goods vehicles like, trucks and vans.

Table 4.2. Changes in vehicle composition and annual growth rate in Delhi (in %)

Year	Motorcycle & Scooter	Car & Jeep	Auto-rickshaw	Taxi	Bus	Truck & Van	All modes
1971	53.47	30.15	5.30	2.01	1 60	7.48	100
1981	65.89	22.34	3.77	1.00	1 62	5.39	100
1985	68.84	18.75	3.57	1.01	1.61	6.23	100
1988	66.37	22 23	3.30	0.70	1.23	6 17	100
1989	67 98	21.08	3 60	0.59	1 09	5 67	100
1993^P	67 94	21.84	3 40	0.51	0.97	5.34	100
Average annual growth rate (%)							
1971-81	12.90	7.30	6.86	3.10	10.67	6.99	10 56
1981-85	12 08	6.11	9.34	11.21	10.71	14.95	10 86
1985-89	17.75	21.63	18.36	3.30	7 11	15.38	18.12

^{P} Provisional

Source. *ACMA, 1993 and NIUA, 1994.*

Table 4.2 also presents the average annual growth rate of various motorized modes during three different periods: 1971-81, 1981-85 and 1985-89. One noticeable feature about the growth is the explosion in the number of two wheelers and cars and autorickshaws during the period 1985 to 1989. The annual growth rate of cars in Delhi is even higher (21.63%) than that of two wheelers (17.75%). The growth rate of buses are lagging behind the personalized vehicles, leading to road chaos and congestion. The intermediate public transport mode like three wheeler - autorickshaw - is emerging out to be an important mode with annual growth rate of 18.36%. The present industrial policy of the Government with regards to transportation equipment has been lopsided due to greater emphasis on production of cars and two wheelers rather than buses. At the national level, car and two wheeler production has gone up by over 6% and 8% per annum whereas the growth rate of bus production is less than 1% between 1986 and 1991 (*ACMA, 1993*).

Delhi has a radial transportation network and for its intra-city trips depends exclusively on the road-based system. It also has a ring railway corridor, the role of which in meeting the travel demand is insignificant.[1] Delhi is perhaps the only city of its size in the world which solely depends on buses for its intra-city mass transport needs The bus system is operated by Delhi Transport Corporation (DTC) assisted by private operators. Even though DTC has achieved the highest productivity amongst city bus undertakings in the country and carries about 5 million passengers daily, it has not been able to meet the expectations of Delhi commuters. The basic reasons for this are the ever increasing average trip length (14 km in 1988-89), with correspondingly increasing journey time of 55 to 60 minutes, and the very high peak hour trips to be carried on several routes. The bus services are overcrowded and unreliable with long waiting period at bus stops and generally unsafe for travel. To provide a better public transport service, more number of buses by private operators were started in 1993 in a phased manner. This includes Redline and Whiteline buses in addition to the existing fleet of about 4200 DTC buses. The idea behind introduction of new buses was to provide the commuters with better service, reduce waiting time and an option to shift to public transport from private transport.

Even though the road availability in Delhi (represented in terms of road length per 100 sq. km. of the urban agglomeration area) is highest in India with 1284 km of road length per 100 sq.km.,the road length is inadequate in comparison to the volume of the traffic. (*Bureau of Economics and Statistics, 1990*).

The congestion on roads can increase either because the road length and/or width is inadequate for the traffic carried or due to the predominance of personalized vehicles which occupy more road space per passenger carried. A good measure to indicate the level of road congestion could be Passenger Car Units (PCUs) per unit of time. The roads in Delhi carry a traffic volume of 6000 PCUs per hour and this goes up to as much as 12,000 PCUs per hour during peak hours in certain areas. The ITO bridge in Delhi, constructed in 1964-65, was designed to carry 40,000-45,000 PCUs, but it now carries about 100,000 PCUs (*NIUA, 1994*). It has been estimated that if the present trends of vehicles continue to grow in Delhi, buses and personal vehicles together will exceed the capacity of road network and cause breakdown of the system, endless delays and loss of energy in the coming years.

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[1] No data is available on travel demand catered by ring railway.

Congestion

Journey speeds are one of the critical factors affecting the fuel consumption and emissions. There is sufficient evidence available suggesting that traffic congestion is increasing with the consequent decline in journey speeds on roads in Delhi, particularly in the central are as of the city. A study carried Delhi (*GOI, 1987*) reveals the following:

- overall speed of cars in Delhi are 20-25 km/h;
- within the central areas the journey speeds are critically low, ranging from 5 to 12 km/h;
- speeds are decreasing in spite of road improvement program.

Due to the existing resource crunch, the program for the additional road space is affected. Thus, the entire success of the future road transportation system would depend on the optimization of the existing road space by designing a system so as to carry more people with less vehicles.

Vehicle ownership

Vehicle ownership per thousand population shows that the two wheelers have increased by more than three and a half times from 1973 to 1989, while during the same period cars and jeeps have gone up by almost double (Table 4.3).

Table 4.3. Vehicle ownership pattern in Delhi

Vehicle type	Vehicle per 1000 population				
	1973	1977	1981	1985	1989
Car and Jeep	17	19	22	22	32
Motorcycle and Scooter	35	50	64	81	128

Source: *TERI, 1994.*

A household survey in Delhi have shown that, apart from car and motorcycle, bicycle also is a dominant mode among the lowest income households in Delhi (*TERI, 1990*) Table 4.4 gives the personal vehicle ownership pattern across different income groups during 1989. The motorcycle and scooter are the predominant modes of transport in Delhi as nearly 45% of households owned this type of vehicle, followed by car 15% and bicycle 13%

respectively. Some households also owned more than one mode of transport. Around 49% of households did not have any vehicle of their own and had to totally depend on public transport. The bicycle ownership declines with increase in household income (Table 4.4). While in the highest income households, the ownership of motorcycle and car is significant (64% and 35% respectively).

Table 4.4. Percent of households with different vehicles in Delhi (in %)

Household monthly income in 1989	Motorcycle & Scooter	Car & Jeep	Bicycle
up to Rs. 1000	11.40	-	36.49
Rs. 1000 - Rs 2500	38.89	1.31	13.40
Rs. 2500 - Rs. 5000	53.38	10.14	10.81
over Rs. 5000	64.11	35.19	2.44
All together	44.88	14.85	13.27

Note: Due to multiple vehicle ownership, the percentage of households with and without a vehicle does not add up to 100.
Source: *TERI, 1990.*

The general conclusions that can be drawn from the survey data are:

- declining trend in cycle ownership with increase in income;
- increasing ownership of motorcycle and car with increase in income;
- predominance of walking and use of public transport in localities near Central Business District (CBD); and
- greater car usage (in highest income households) in localities distant from the city center as compared to localities near CBD.Though vehicle ownership in Delhi is increasing rapidly but quite low compared to that in the cities of developed countries, the problem is complex due to the wide range of vehicle types. The rise in production of two-wheelers and cars during the last ten years has been phenomenal.

With the technology import liberalization policy of the government, and the establishment of several international collaborations, the automobile policy in 1985 allowed the manufacturers to produce any type of vehicle, from passenger cars to heavy commercial vehicles (HCV) with no constraint on engine size or any attempt at obtaining an appropriate mix of vehicles from the viewpoint of fuel efficiency, pollution, axle load, chassis configuration, road damage and minimization of total transport costs. The liberalization policy has thus lead to fragmentation in production and lack of standardization. For example, Delhi, with approximately 1% of the total population of the country in 1991, accounted for 10% of the total registered vehicles in the country.

Travel pattern

While an estimated 12.7 million person-trips were made daily in 1990, the annual growth rate of urban travel is 9.5% in Delhi (*NCU, 1988*). About 43% of all trips were for work purposes and 31% for education purposes during 1981 (*Patankar, 1989*). The purpose-wise trips reveal, that Delhi is an educational center besides being the seat of administration. Table 4.5 gives the trend of person trips by purpose worked up as percentage of total.

Table 4.5. Trips purpose in Delhi (in %)

Purpose	1957	1969	1981
Work	77	59	43
Education	8	16	31
Other	15	25	26

Source· *Patankar, 1989.*

About 75% of the educational trips, 25% of the work trips and about 50% of the total person trips in Delhi are walk trips (*CRRI, 1990*). The majority of walk trips in Delhi are performed within a reasonable walk distance of about 2 km length. Urban planners therefore need to pay attention to the needs of pedestrians while designing the cities. Bus caters to over 32.5% of the total trips in Delhi, while 15.4% is catered by private vehicles - which include cars and motorcycles/scooters Over 2% of trips are catered by 3-wheeler autorickshaws and non-motorized modes mainly bicycles.

The average bus trip length in Delhi is 14 km which is highest in the country. The distribution of bus trip lengths are: up to 6 km (12.5%), 6-12 km (44%), 12-18 km (34%) and above 18 km (9.5%). Charter buses are used for longer trip lengths. The trip length for work ranges between 6 and 10 km, whereas for education, it works out to 2 to 4 km.

Safety

The heterogeneity of vehicular traffic, sharp peaking of traffic volumes and increased dependence of personalized modes for essential trips on one side and design of roads and intersections and lack of enforcement measures on the other, are some of the major causes of both personal injury as well as total accidents in Delhi. The number of fatal accidents is increasing every year. For instance, in Delhi, the number of fatal accidents increased by 6% annually between 1989 and 1991 (1460 fatal accidents in 1989, 1559 in 1990 and 1651 in 1991). During 1992, Redline buses (run by private operators) were started in Delhi and alarmingly high rates of accidents were caused by these buses within one year (183 fatal accidents in 1993) as compared to the DTC buses. About 2 million motor vehicles plying on 19,084 km long roads in Delhi claim 4% of the total fatalities that occur in the country (*NIUA, 1994*). The capital's 50 km long freeway, Ring Road, has several accident-prone zones and bottlenecks.

Travel demand

Passenger travel demand of each transport mode - expressed in passenger kilometer (pkm) - is obviously the product of:

- the total number of vehicles of any type;
- the average distance travelled by each vehicle;
- the 'useful' service provided by each unit of distance travelled, such as passengers carried or the average occupancy of the vehicle.

However, the total passenger travel demand in a given area is the sum of the products of different vehicles used to cater the total travel demand.

Using this relationship, the growth in passenger travel demand in Delhi is estimated from 1981/82 to 1988/89 and is presented in Table 4 6. The same table also gives the change in modal split of vehicles in Delhi during the same period.

Table 4.6 reveals that the total travel demand catered by motor vehicles in Delhi increased at the rate of 9.2% annually during the period 1981/82 to 1988/89, with more and more dependence on personal transport modes like motorcycle, scooter and car. However, the travel demand catered by bus have declined from 78% in 1981/82 to 72% in 1988/89. Interestingly, the share of travel demand catered by autorickshaw (3-wheeler) have remained constant at about 2% during the same period. The inadequate mass transit system is the basic cause of large number of personalized vehicles and autorickshaw.

Table 4.6. Estimated passenger travel demand and modal split in Delhi - 1981/82 to 1988/89

Vehicle	Number of vehicles (thousand)[a]				Occupancy[b]	Effective utilization km/y	Estimated travel demand (10^9 pkm)			
	1981/82	1985/86	1986/87	1988/89			1981/82	1985/86	1986/87	1988/89
Car/Jeep	130	166	221	299	2.6	9500	3.21 (7.61)	4.10 (6 33)	5.45 (7.58)	7.38 (9.44)
2-wheeler	367	579	770	865	1.6	9000	5.28 (12.52)	8.34 (12.88)	11.09 (15 41)	12.46 (15.93)
3-wheeler	21	30	35	43	1.8	25000	0 95 (2.24)	1.35 (2.09)	1.56 (2.16)	1.95 (2.49)
Bus	9	14	15	16	52	70000	32.76 (77 63)	50 96 (78.70)	53 87 (74 85)	56.42 (72.14)
All together	527	789	1040	1223	-	-	42 20 (100)	64.75 (100)	71 97 (100)	78 21 (100)

Figures within brackets are modal split values.
Source: [a]*ACMA, 1990*; [b]*GOI/ESCAP, 1991.*

Mass rapid transit system plan for Delhi

To meet the complex and ever growing transportation requirements of Delhi, and keeping in view the ever increasing vehicle population in Delhi, growing traffic congestion, the limitations of the road based bus system resulting in overcrowding of public transport system and poor conditions for pedestrians and cyclists, increasing incidence of road accidents, commuter suffer long waiting and journey time, alarming urban air pollution levels, and also the threshold limit of the widening of existing road network, an integrated Mass Rapid Transit System (MRTS) in Delhi is strongly suggested by the experts. According to a study conducted by the Rail India Technical and Economic Service (RITES), the proposed multi-modal MRTS scheme comprises of components of existing rail corridors, a metro corridor and a high capacity bus system In fact, the Master Plan for Delhi-2001 suggested introduction of multi-modal transport system including electrified ring rail, bus transport, MRTS and Light Rail Transit System (LRTS). The Ministry of Urban Development, Government of India is considering a MRTS scheme for Delhi at a total estimated cost of Rs. 53.79 billion[2] (at 1989 price level) which has not been approved for implementation for want of funds (*TERI, 1993*).

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[2] Rs. 25.55 billion during the first phase and Rs. 28.33 billion for remaining phase.

The proposed 144 km surface rail corridor would be comprised of the existing underutilized ring railway and seven spurs connecting the regional towns of Ghaziabad, Faridabad, Gurgaon, Ballabhgarh, Sonepat and Loni. Figure 4.4 is a lay out plan of the MRTS for Delhi. The underground metro rail system would cover 41 km and consist of two corridors - the East-West (24 km) and the North-South (17 km). The high capacity bus system for the MRTS would cover a distance of 12 km (from Patel Nagar to Papankala). According to its implementation plan, the project will be completed in two phases - first phase by 2001, while the second and final phase by 2011.

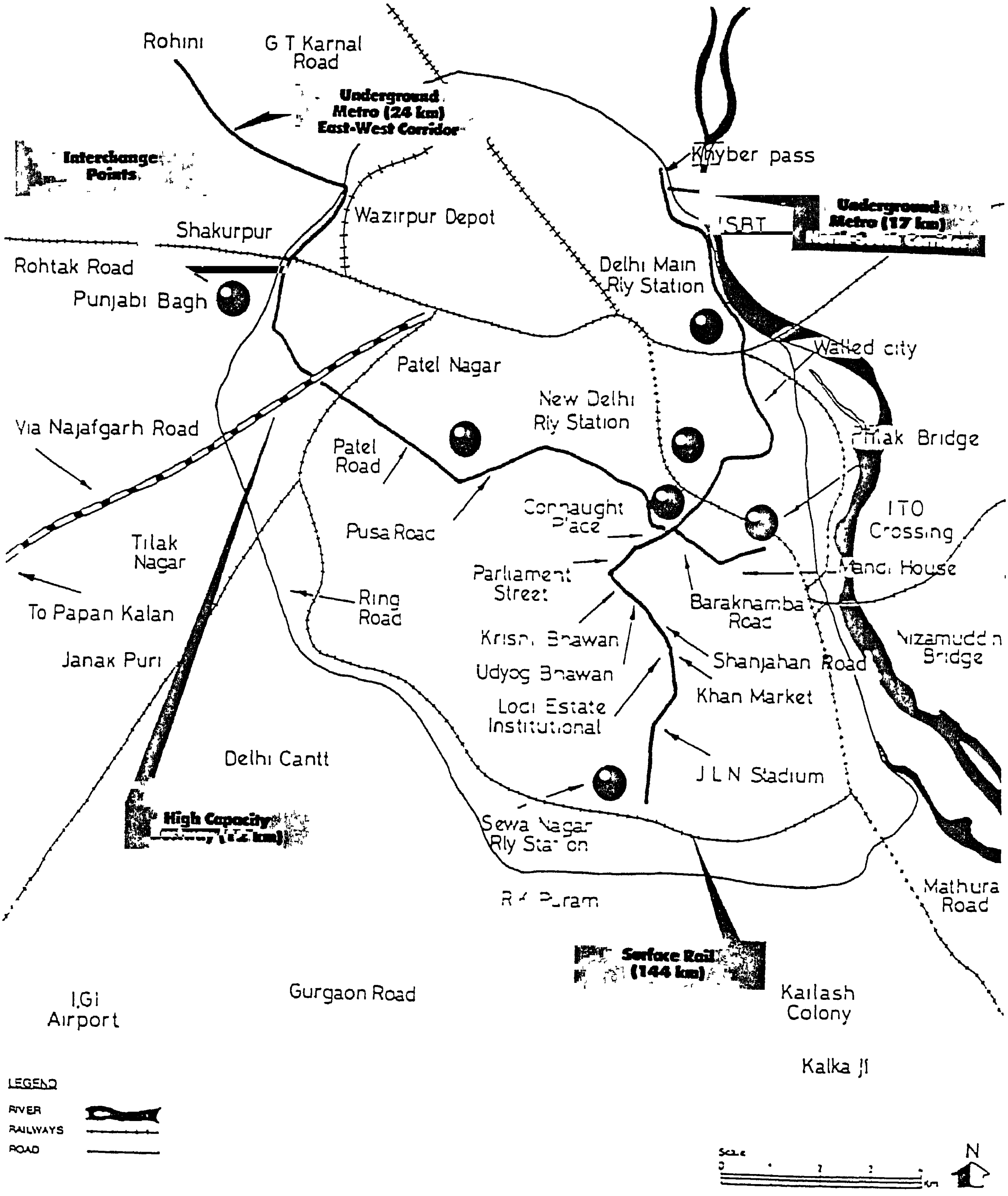
Energy demand and emissions from the transport sector

The two major fuels used for the propulsion of motor vehicles in Delhi are gasoline and diesel. Gasoline is exclusively used in light weight passenger road transport vehicles, like two-wheelers, three-wheelers and cars/jeeps/taxis. While diesel is used in buses and goods vehicles apart from its use in industry and agriculture. In the recent years about 75% of cars/jeeps/taxis are run on gasoline and remaining 25% on diesel (*ACMA, 1993*).

The composition of exhaust from motorized vehicles is characterized by emission of carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NO_x), sulfur dioxide (SO_2), lead (Pb) and total suspended particulate (TSP). In the absence of any control on the emission from vehicles, exhaust gases would continue to contribute air pollution significantly. These pollution problems are further compounded when atmospheric conditions are stable and there is no vertical mixing or motion of air. In the diesel engine exhaust, the concentration of CO and unburnt HC are low, but NO_x is very high Smoke particulate, oxygenated hydrocarbons and other odorous gases are present. In gasoline or petrol driven cars exhaust tail-pipe emissions account for entire CO, NO_x, and Pb/Pb derivatives emissions In two and three wheelers, powered by 2-stroke engines, exhaust emissions are the principal source of pollutants. The inherent weakness of the existing design of 2-stroke engines in India is that 25-40% of the fuel supplied is discharged without being combusted. This results in a large addition of unburnt HC. In 2-stroke engines, emissions of CO is almost the same as that in 4-stroke engines, but NO_x discharge is much less.

To extrapolate total and disaggregate (by different transportation modes) energy demand and resultant emissions due to the growth in passenger travel demand, a simple model is developed using a computer based software called - Long Range Energy Alternatives Planning (LEAP) and the associated Environmental Database (EDB) model (*Bose*

Figure 4.4. Proposed Mass Rapid Transit System



Urban Environmental Maps

National Institute of Urban Affairs New Delhi *and Mackenzie, 1993*).[3] The central concept of LEAP is an end-use driven scenario analysis. In this approach, the computer system is used to analyze the current energy scene and to simulate alternative energy futures along with emissions under a range of user-defined assumptions. LEAP emphasizes the detailed evaluation of specific energy problems within the context of integrated energy and environmental planning for each "what if" scenario - or combination of scenarios.

The hierarchical structure of LEAP represents the traffic patterns in terms of passenger travel demand, mode (rail/road), type of vehicle and occupancy (persons per vehicle). Transport database in Delhi together with fuel consumption values for the vehicle types, formed the basis of the transport demand and energy consumption calculations. Emission factors corresponding to the actual vehicle types and driving conditions in Delhi is introduced into the EDB and linked to the energy consumption values for estimating total emission of CO, HC, NO_x, SO_2, Pb and TSP. The LEAP model is used to estimate total energy demand and the vehicular emissions for the base year - 1990/91 and extrapolate for the future - 1994/95, 2000/01, 2004/05 and 2009/10 respectively.

The model results are obtained under four alternative scenarios to study the impact of different urban transport policy initiatives that would reduce total energy requirement in the transport sector of Delhi and also reduce emission. The extent of fuel savings and reduction in total emissions are estimated under alternative scenarios and then compared with the business-as-usual (BAU) scenario. Each of these scenarios are described below:
Scenario 1: *Business as usual scenario (BAU)* This scenario assumes that the present trends of vehicular growth in Delhi will continue, and fuel efficiency norms, modal split pattern and occupancy levels will remain unchanged till 2009/10 from 1990/91 observations.

Strategies to contain growth of fuel consumption and emissions

Scenario 2: *Improvement in the vehicular speed.* It is assumed that through appropriate traffic management measures, travel speed on Delhi roads will increase from an average present speed of 20 km h^{-1} to 40 km h^{-1} (energy efficient speed) by 1994/95 for all types of vehicles. With this, fuel efficiency will improve for each mode of passenger vehicles. This would bring an overall saving of gasoline and diesel oil and also reduce pollution levels when compared with the BAU scenario.

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[3] LEAP is an energy planning system developed at the Stockholm Environment Institute (SEI), Boston. The system includes an EDB developed with support from the United Nations Environment Programme (UNEP) and is a joint UNEP/SEI activity (*Lazarus M., etal., 1993*).

Scenario 3: *Increase the share of buses.* It is assumed that through appropriate transport policy interventions, there will be an increase in the share of buses during 2000/10 to the level observed in 1981/82. In other words, modal split during 2000/01 will be brought to the same level as was the case in Delhi during 1981/82. Thus in scenario 3, a large portion of the passenger travel demand in Delhi will be met by bus services thereby it would bring overall efficiency of passenger movement. The extent of total petroleum demand will therefore reduce in this scenario along with reductions in emission levels, when compared with BAU scenario.

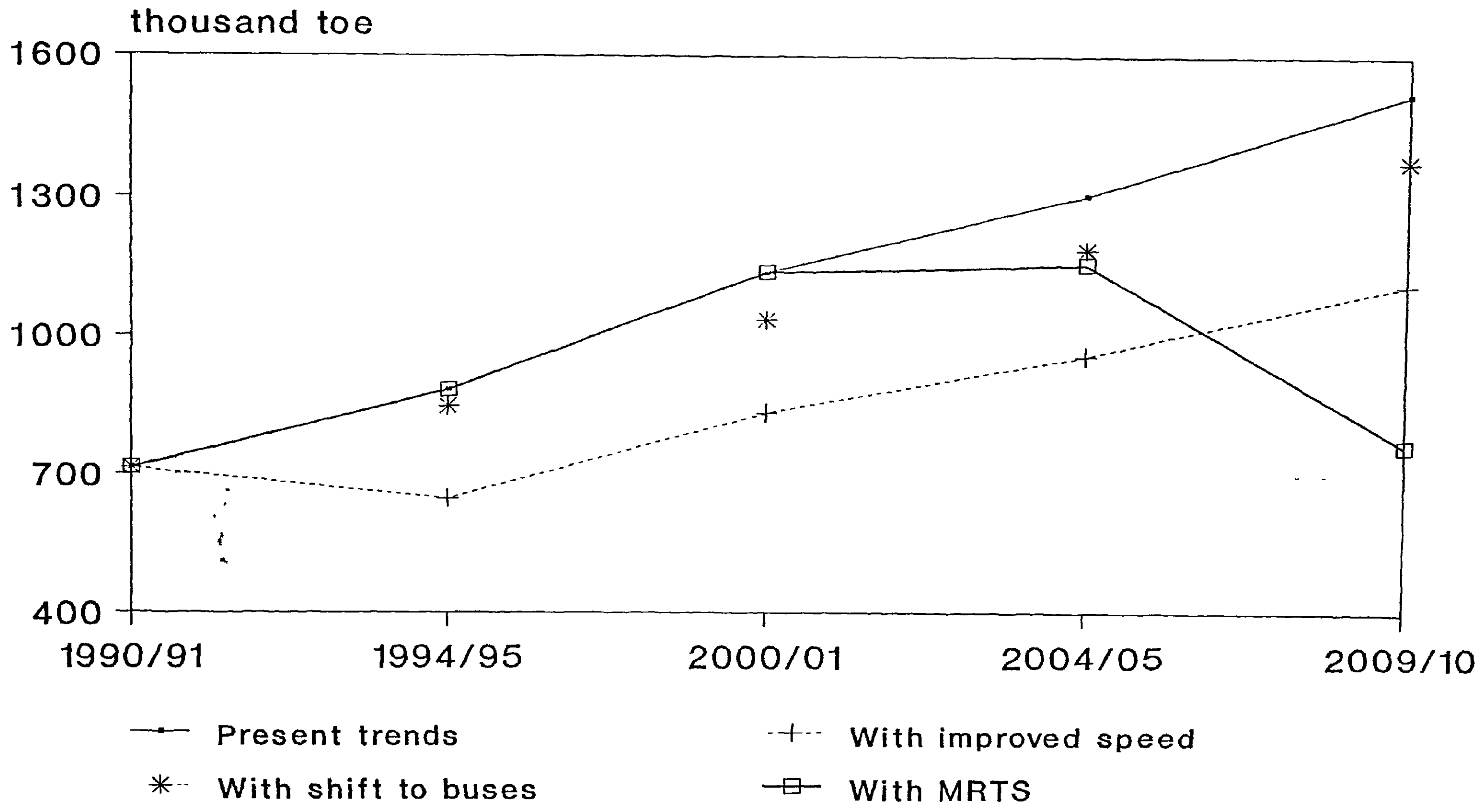
Scenario 4: *Introduce mass rapid transit system (MRTS).* It is assumed that the integrated multi-modal MRTS is introduced in this scenario by 2004/05 and continues to grow further in phases till the full capacity of MRTS is achieved in 2009/10 (*RITES, 1989*). It is estimated that the per cent share between roadways and railways for 2005 and 2010 would be 87.60:12.40 and 74.56:25.44 respectively (*TERI, 1993*). This means that by 2004/05, a portion of passenger road transport will be substituted by railway and would save petroleum demand over future years and also reduce emission levels, as compared with BAU scenario.

LEAP model results and analysis

Scenario runs are made to estimate energy demand in the transport sector of Delhi for 1990/91 (base year), and extrapolated for the years 1994/95, 2000/01, 2004/05 and 2009/10 (*Bose, 1995*) Figure 4.5 presents the energy demand estimates. Consumption of gasoline and diesel together for meeting passenger travel demand, in Delhi, is estimated to be 713,470 tonnes of oil equivalent (toe) for the base year 1990/91. Of this total energy demand, gasoline consumption is about 62 per cent (442,300 toe) and the rest 38 per cent (271,170 toe) is diesel oil. The demand figures are compared with actual consumption of gasoline and diesel in Delhi during 1990/91. It is observed that the gasoline demand, according to the model estimate is 20 per cent higher than actual consumption. Higher estimates of gasoline consumption in Delhi could be due to use of normative values of fuel efficiency and trip length, under a typical urban driving cycle. However, under actual driving conditions on urban corridors, these parameters will vary and would influence the total gasoline requirement.

Total gasoline sold in Delhi increased from 127,275 toe in 1973/74 to 389,001 toe in 1992/93 indicating an annual growth rate of 6.1%. During the same period, total diesel sold in Delhi grew much rapidly at the rate of 9% per annum - from 157,598 toe in 1973/74 to 808,905 toe in 1992/93 (*GOI, 1974-93*). By assuming these growth rates, total gasoline and diesel requirement in Delhi, is estimated to be 624,703 toe and 1,611,794 toe respectively during 2000/01. Though gasoline is consumed by passenger modes of vehicles

Fig.4.5.Transport energy demand in Delhi for passenger travel



Source: Bose, 1995

only, diesel however is consumed in different sectors, viz., industries, power plants, freight transport and public transport.

But, according the model estimates, gasoline and diesel requirement for passenger transport alone would be of the order of 705,200 toe and 432,550 toe respectively during 2000/01 in the BAU scenario. The question is, can we really meet this large demand of petroleum fuels only to cater the passenger travel requirement? Of course, the answer is no. Although the energy demand for road transport has increased considerably over the last two decades, the average vehicle miles travelled per unit of fuel consumed have shown marginal improvement.

The model estimates under different scenarios, have shown how with different policy interventions, energy demand in the transport sector could be reduced. In the case of diesel, over one third of the total diesel oil is consumed by passenger transport in Delhi, while the remaining two-third is shared by industry and freight transport. The share of buses in the total energy consumption (713,470 toe) is 37% in 1990/91. The share of car and jeep together is 33%; two wheelers with 23%, and three wheelers with 7% respectively

Apart from energy demand figures, vehicular emissions of CO, HC, Pb, NO_x, SO_2, and TSP, are also estimated by the LEAP model for the reference years under alternative scenarios. Estimated loading of these pollutants is given in Table 4.7.

In addition, the model estimates the relative contribution of gasoline and diesel vehicles to air pollution. The loading of various pollutants in Delhi during 1990/91 is estimated to be CO (179,590 t); HC (73,000 t); Pb (100 t); NO_x (16,120 t); SO_2 (2,270 t) and TSP (360 t) respectively. Gasoline driven vehicles are responsible for as much as 97% of CO and HC loading while the diesel driven vehicles produce the remaining 3% Gasoline driven vehicles also contribute 32% of the total NO_x emission, and 15% of SO_2 emission. Also, only gasoline vehicles contribute Pb emission. On the other hand, diesel vehicles only contribute TSP (diesel smoke) emission. These pollutants are known to have adverse effects on the health of human beings and animals. They also cause damage to vegetation, materials and buildings. Additionally, HC and NO_x emissions undergo photochemical reactions and generate several secondary pollutants e.g., peroxy benzyl, acyl nitrates, aldehydes etc. which are irritants to the eyes, nose and throat (*IIP, 1985*).

Air quality

Delhi is the most polluted city in India and fourth most polluted city in the world. More than half of the total atmospheric pollution in Delhi, comes from the emission of over 2 million motorized vehicles that cough up 179,590 t of CO; 73,000 t of HC; 100 t of Pb; 16120 t of NO_x; 2,270 t of SO_2; and 360 t of TSP respectively (*Bose and Mackenzie, 1993*).

Table 4.7. Annual emissions (in thousand tonnes)

Alternative scenarios	1990/91	1994/95	2000/01	2004/05	2009/10
Scenario 1: As per present trends (BAU)					
CO	179.59	222.28	286.33	329.05	382.42
HC	73.00	90.35	116.39	133.75	155.44
Pb	0.10	0.13	0 17	0.19	0.22
NO_x	16.12	19.95	25.70	29.53	34.32
SO_2	2.27	2.81	3.63	4.17	4.84
TSP	0.36	0.45	0.58	0.67	0.77
Scenario 2· Improvement in vehicular speed					
CO	179.59	184.21	237.29	272.69	316.92
HC	73.00	76.58	98.64	113.35	131.74
Pb	0.10	0.11	0.14	0.16	0.18
NO_x	16.12	12.88	16.59	19.06	22.16
SO_2	2.27	1.73	2 22	2.55	2.97
TSP	0.36	0.26	0.33	0.38	0.44
Scenario 3 Increase the share of bus					
CO	179.59	203 22	268.22	268 01	311.48
HC	73 00	82.88	94.72	108 85	126.51
Pb	0.10	0.12	0 13	0.15	0 18
NO_x	16.12	19.86	25.42	29 22	33.95
SO_2	2.27	2.86	3.74	4.30	5.00
TSP	0.36	0.46	0 62	0.72	0.83
Scenario 4. Introduce mass rapid transit system (MRTS) using electricity					
CO	179 59	222.28	286.33	288.24	191.62
HC	73.00	90.35	116.39	117.16	79 55
Pb	0.10	0.13	0.17	0 17	0 11
NO_x	16.12	19.95	25.70	25.87	15.99
SO_2	2.27	2.81	3.63	3 65	2.25
TSP	0.36	0.45	0.58	0.58	0.35

Source: *Bose, 1995.*

(a) Carbon monoxide: The major source of CO emissions in Delhi is transport. In 1990, total CO emissions were estimated around 265,000 tonnes per annum and is likely to reach 400,000 tonnes per annum by the year 2000 (*NEERI, 1991*). On comparing these total emission figures with LEAP estimates under the business-as usual (BAU) scenario, it is observed that during 1990, as high as 68% of the total emissions in Delhi was only from passenger transport and the corresponding share is likely to increase to 72% during 2000/01. A study conducted by the Central Road Research Institute, New Delhi at 20 major intersections and involving 120 policemen revealed that traffic policemen at 3 intersections were exposed to 20 times the permissible CO concentration level of 5000 $\mu g/m^3$ (*CPCB, 1990*).

(b) Nitrogen oxides: Total emissions of NO_x were around 73,000 tonnes per annum in 1990. Industrial emissions accounted for around 15,000 tonnes per annum during 1980s. More than 90% of industrial NO_x emissions are from thermal power stations. With the increase in diesel vehicles, transport NO_x emissions have increased significantly and will continue to increase in future. Diesel driven goods vehicles and buses are important sources of NO_x emissions. On comparing these total emissions with the results of the LEAP model, it is observed that around 22% of the total NO_x during 1990 was from passenger vehicles It may be mentioned here that since the LEAP framework has not considered goods vehicles (which are primarily diesel driven trucks) the corresponding share of NO_x emission is relatively lower. Further, diesel vehicles will account for 96% of vehicular NO_x emissions (*NEERI, 1991*) The annual mean concentration of NO_x in Delhi is well below the permissible level of 120 $\mu g/m^3$ during 1990 (*CPCB, 1990*)

(c) Sulphur dioxide: The industrial sources, thermal power stations in particular, are responsible for majority of SO_2 emissions in Delhi. The power stations in Delhi produce around 25,500 tonnes of SO_2 per annum. Total anthropogenic SO_2 emissions are estimated approximately at 45,000 tonnes per annum in 1990 with a projected increase to 49,000 tonnes per annum by 2000 (*NEERI, 1991*). With the growth in the number of vehicles, SO_2 emissions from transport sector have increased and will continue to increase. On comparing these total emissions with the results of the LEAP model, it is observed that around 5% of the total SO_2 during 1990 was from passenger vehicles, which is likely to go up to 7% during 2000 under the BAU scenario. The corresponding share would have increased with inclusion of goods vehicles in the LEAP model. The number of diesel driven vehicles (the major source of vehicular SO_2 emission) have increased from 16,658 in 1971 to 75,709 in 1987 (*NIUA, 1994*). Though the annual mean concentration of SO_2 in Delhi has been also well below the standard limit of 120 $\mu g/m^3$ during 1990 (*CPCB, 1990*), but its mean concentration in winter months (December-February) is generally higher than the rest of the months in the year.

(d) Total suspended particulate: Total TSP emissions during 1990 was around 115,700 tonnes per annum (*NEERI, 1994*). Particulate emissions are estimated to increase to 122,600 tonnes per annum by 2000. Increasing TSP emissions are attributed to industries especially the ceramic (brick) industries which are the major sources of TSP after power stations. Anthropogenic emissions are not the only source of TSP in Delhi. Natural dust storms which blow in pre-monsoon period increases the concentration of particulate considerably in the atmosphere. This natural dust remains in circulation for longer periods. Road transport (only the diesel driven vehicles) add considerably to anthropogenic TSP in Delhi. Estimates from the LEAP model shows that less than 1% of the total TSP emissions in Delhi is from diesel buses. The corresponding share will increase with the inclusion of diesel driven goods vehicles, which has not been considered in the LEAP framework. In fact, annual emissions from the road transport sector in Delhi was found out to be 3% of the total emissions in Delhi during 1988/89, while the share from the other economic sectors were - industry (67%), power plants (27%), domestic (2%) and commercial (1%), respectively (*Bose, 1990*) The annual mean concentration of particulate matter is higher than the prescribed limits of 500 $\mu g/m^3$ for industrial areas; 200 $\mu g/m^3$ for residential areas and 100 $\mu g/m^3$ for sensitive areas (*CPCB, 1990*). The summer months (May-June) have concentrations as high as 1500 $\mu g/m^3$. Natural dust storms which blow in the city during summer, causes higher concentrations of particulate matter. Undoubtedly, the particulate matter poses pollution menace for almost throughout the year.

Finally, with regard to Pb and HC emissions in Delhi, there is hardly any information available from secondary sources.

Scenario analysis

Scenario 1: This is the business-as-usual (BAU) scenario, in which modal split and average traffic speed remain unchanged and vehicle populations continues to grow The energy demand is estimated at 883,090 toe; 1,137,550 toe; 1,307,240 toe; and 1,519,270 toe for the years 1994/95, 2000/01, 2004/05 and 2009/10 respectively (Figure 4.5). The fuel requirement under BAU scenario will more than double by 2009/10 vis-a-vis 1990/91 and so will the loading of different pollutants (Table 4.7). Out of the total estimated energy demand, buses in Delhi will consume the greatest share of oil (37%), followed by cars and jeeps (together 32%), two wheelers (23%) and three wheelers (7%) respectively. The principal emissions from gasoline vehicles are CO (97% of the total emissions), unburnt HC

(97%) and Pb (100%); whereas for diesel vehicles the principal pollutants are TSP (100%), NO_x (68%) and SO_2 (85%) respectively.

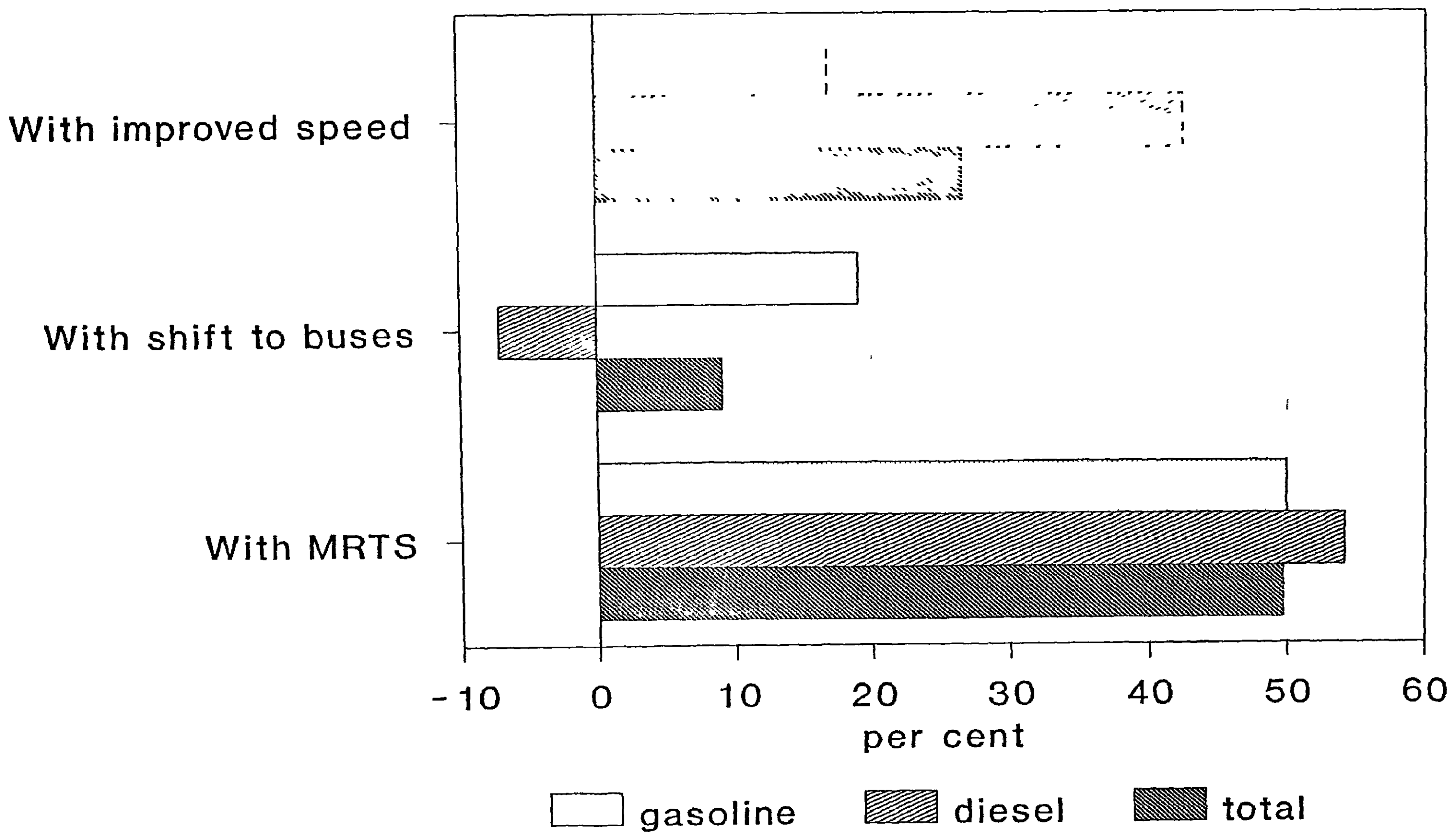
Scenario 2: One of the critical factors affecting energy efficiency in urban transport is journey speed. The limited data on the effect of journey speed on fuel consumption have shown that, in general, the optimum level of fuel consumption for different vehicles lies in the range of 40 and 50 km/h. Therefore, scenario 2 investigates the effect on total energy demand and pollution loading that could be achieved through appropriate traffic management measures, increasing the average speed for all types of vehicles on all Delhi roads from the present level of 20 km/h to 40 km/h by 1994/95.

There is an overall saving of nearly 27% of total energy requirement in the future if scenario 2 is implemented (Figure 4.6). The reduction in gasoline demand is estimated to be 17% and diesel demand 42%. There is an overall reduction of emissions of different pollutants. Reduction in loading of CO, HC, Pb, NO_x, SO_2 and TSP during 2009/10 is presented in Figure 4.7. Maximum reduction is observed in the case of TSP (between 42 and 43 per cent), followed by SO_2 (38 per cent), NO_x (35 per cent), Pb (between 15 and 18 per cent), CO (17 per cent) and HC around 15 per cent.

Scenario 3: Under this scenario, the model has estimated total energy demand if the share of bus goes up from 72% in 1990/91 to 78% by 2000/01, which was the situation in Delhi during 1981/82. There is a drop in total fuel demand by 9% from 2000/01 onwards, as compared to scenario 1, with reduction in gasoline demand by 19% But, since more buses are added to the fleet, diesel demand goes up by 7%. Whereas during 1994/95, the extent of fuel savings is only 4%, with gasoline savings around 8% but diesel demand increasing by 3% It may be noticed here that out of the total energy requirement, the share of diesel in buses goes up from 40% in 1994/95 to about 44% in 2009/10. On the other hand, dependence on gasoline vehicles is reduced.

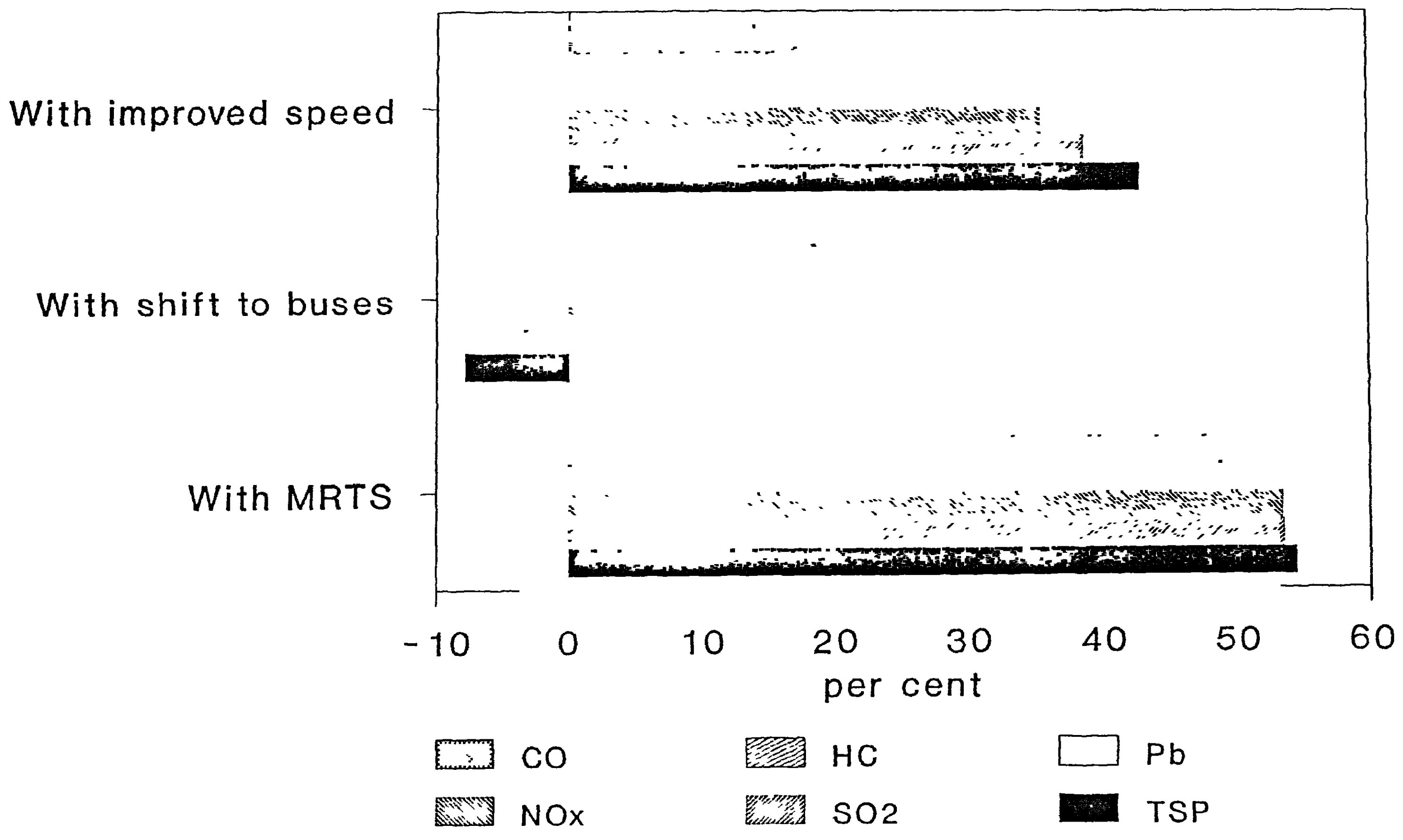
With more buses on road, there is an overall improvement as far as emissions of CO, HC and Pb is concerned (Table 4.7) with respect to scenario 1 Reduction in loading for these three pollutants is about the same i.e., 8% during 1994/95. However, for the years 2000/01, 2004/05 and 2009/10, the reduction in emission of CO and HC compared to BAU is around 19%. For Pb there is an overall reduction of 24% in 2000/01, 21% in 2004/05 and 18% in 2009/10 respectively due to substitution of gasoline driven vehicles by diesel driven buses. With more public buses on the road, contribution share of principal pollutants emitted from gasoline vehicles will come down.

Fig.4.6.Energy savings in 2009/10 with respect to BAU scenario



Source: Bose, 1995.

Fig.4.7.Emissions reduction in 2009/10 with respect to BAU scenario



Source: Bose, 1995.

Scenario 4: Here it is assumed that Delhi will have a portion of MRTS ready for operation in 2004/05 and it will meet nearly 12% of the total passenger travel demand. However, by the terminal year 2009/10, when MRTS is operational in its full capacity, its share in the total travel demand will be around 25%. In this scenario, apart from gasoline and diesel, electricity will also be required for the rail based passenger transportation system. Under such assumptions, Figure 4.5 reveals that total energy demand will go down by 12% in 2004/05 and the reduction will be about 50% in 2009/10. There is an overall reduction of gasoline and diesel demand, each by around 12% in 2004/05. Gasoline demand would decline further to 50%, while diesel demand would go down by 54% in 2009/10. During 2004/05, nearly 1% of the total energy demand in the passenger transport sector will be in the form of electricity for MRTS and its share will go up to about 3.6% by 2009/10. Reduction in pollution emissions is observed from 2004/05 as compared to BAU. CO, HC, NO_x and SO_2 emissions are reduced, each by about 12%, Pb by 11% and TSP by 13% in 2004/05. In the terminal year, annual CO and Pb emissions will reduce to half as compared to the BAU scenario. While the corresponding reduction of HC emissions will be 48%, NO_x (53%), SO_2 (53%) and TSP (55%) respectively.

The BAU scenario, in which present trends in transport demand, modal split and fuel economy are assumed to continue, has shown a dramatic increase in energy demand and the resultant emissions. The alternative scenarios have shown how the increase in energy consumption and pollutant levels can be limited through measures such as increasing the average speed of urban traffic, encouraging a shift to buses, the introduction of new forms of mass transit and through conservation efforts Given that both gasoline and diesel are imported in India, the reductions in fuel consumed in the different scenarios translate directly into foreign exchange saved, which is an independent policy objective. No one measure can alone achieve the gigantic task of containing the growth of fuel consumption and emissions. A successful policy must include a mixture of the above elements.

The study has shown how the LEAP/EDB system, combined with appropriate detailed local data on traffic patterns, energy consumption and emission factors, can provide a valuable tool for assessing future urban transport options in the urban transport sector.

Global environmental benefits due to MRTS

The proposed multi-modal MRTS project in Delhi will reduce significant Carbon emissions by the year 2040 (assuming the life of MRTS to be 35 years). In order to assess Carbon reduction potential, a base line data is required with which reduction scenarios can be compared (*Grubler, 1993*). Usually, the continuation of present trends of vehicular growth, fuel efficiency norms and modal split pattern as exemplified in the BAU scenario provides the basis for such comparisons.

Emissions under the two scenarios - one with MRTS and another without MRTS (or BAU scenario) - are compared to assess the reduction potential of CO_2 emissions. First, CO_2 emissions are estimated under both these scenarios. Next, cumulative reduction potential of CO_2 emissions is estimated with an MRTS in Delhi over the lifetime of the project. Finally, the incremental cost per tonne of CO_2 saved is worked out. The benefits accruing from the reduction of CO_2 emissions provides the justification for implementation of the MRTS project in Delhi.

According to the RITES techno-economic feasibility report, the MRTS project will be completed in two phases (*RITES, 1989*). It is assumed that the first phase of the project will be operational by 2005 and not 2001, thereafter its capacity of operation will keep on adding in each of the subsequent years, till the second and final phase of the MRTS project is ready by the end of 2011, and under operation. It is therefore assumed that the full capacity of MRTS will be achieved in 2011, and would then continue to carry assigned number of trips (9.61 million passengers per day) each of the following years, for the next 30 years (*RITES, 1989*).

Travel demand and rail-road share

Time trend equation is used to project passenger travel demand for 2005 and 2011, using the time series data of growth in travel demand in Delhi between 1981/82 and 1988/89. The equation is given by

$$y = 36.77 + 5.39\ t \qquad R^2 = 0.98 \tag{1}$$

where y denotes the passenger travel demand in Delhi and t = (n+1)-1982 with n as year, denotes the time period.

Using equation (1) annual passenger travel demand is estimated to be 90 65 billion passenger kilometer (BPKM) during 1991; 166.09 BPKM during 2005, and 193 09 BPKM during 2011. This suggests that over a 20-year period (i.e., between 1991 and 2010) the passenger travel demand in Delhi will grow more than twice under the BAU scenario.

An MRTS in Delhi would cater to 4.03 and 9.61 million passengers per day during 2005 and 2011 respectively (*RITES, 1989*). Also, assuming that the average trip length in Delhi would remain same at 14 km over the next 20-years, the total travel demand catered by MRTS would be 4.03x14x365 = 20.59 BPKM in 2005 and 9.61x14x365 = 49.11 BPKM in 2011 respectively. Thus, the share between roadways and railways for 2005 and 2011 is estimated to be 87.60:12.40 and 74.56:25.44 per cent respectively.

CO_2 annual emissions

India has recently experienced dramatic growth in CO_2 emissions, which have increased 5.9% per year since 1950 as India has climbed from 13th to 6th place as a national contributor. Total emissions increased by 10.4 times over this interval, and per capita emissions increased almost 4 times. Emissions in India continue to result largely from coal burning. Coal contributed 87% of the emissions in 1950 and 71% in 1991; at the same time, the oil fraction increased from 11% to 22%. During 1991, national CO_2 emissions was estimated to be 192 million tonnes of Carbon (*CDIAC, 1994*).

Table 4.8 gives the estimated CO_2 emissions in Carbon equivalent in Delhi under both the scenarios (with and without MRTS) using the LEAP framework. In 2005, with 12.4% of total trips catered by MRTS, the CO_2 emission is likely to be 2% higher than without an MRTS in Delhi (Table 4.8). However, as can be noticed from Table 4.8, in the following years, with more and more share of MRTS trips coupled with improvement in energy use efficiency in both power and transport sectors in Delhi, the CO_2 emission will reduce by over 24% by 2011, when compared to the BAU scenario (without an MRTS).

Table 4.8. CO_2 emissions in C equivalent with and without MRTS in Delhi

('000 tonnes)

Year	Without MRTS	With MRTS	Reduction of CO_2 with MRTS
2005	1080	1102	-2%
2006	1115	1080	3%
2007	1150	1059	8%
2008	1185	1039	12%
2009	1220	1018	17%
2010	1255	999	20%
2011	1290	979	24%

Source: *TERI, 1993*; and *TERI, 1994a*.

Total CO2 reduction potential with MRTS

The global environmental benefits (in terms of reduction in CO_2 emissions) due to the implementation of MRTS in Delhi can be justified on the ground of incremental costs of CO_2 saved. For calculating the incremental cost, a time frame of 35 years is chosen (assuming the life of MRTS to be 35 years).

The total saving amounts to about 13992.45 thousand tonnes of CO_2 over 35 years with an MRTS in Delhi (*TERI, 1994a*). The incremental costs for this saving is attributed to:

(a) *Construction and implementation of MRTS*: As estimated by RITES, it will cost Rs 74.69 billion (at 1992-93 price). With an inflation rate of 10%, it would be Rs 82.16 billion.

(b) *Operation and maintenance*: It accumulates to Rs 145.94 billion in 35 years @ 5.79% per year till 2011 and 5.57% after achieving full capacity.

(c) *Electricity generation cost for MRTS*: An utility power plant can be set up for generating the required electricity. It is estimated that the capacity of the power plant is 51 MW for generating the required electricity for MRTS. Hence the associated costs are:

- installation cost @ Rs 35 million/MW = Rs 1.79 billion
- operation and maintenance @ 2.5% of this = Rs 1.56 billion for 35 years
- fuel cost @ Rs 700 per kg of coal = Rs 5 53 billion for 35 years (1 kWh requires 0 68 kg of coal.

Hence, total cost incurred would be Rs 236.98 billion = US $ 7 64 billion (@ $ 1 = Rs 31). Now, due to the introduction of MRTS, there will be considerable saving in the investment in buses which otherwise the government had to incur. The annual savings due to the capital, replacement and operation of buses have been estimated and it amounts to about Rs 230.93 billion ($ 7.45 billion) over 35 years.

Thus, the incremental cost per tonne of CO_2 saved is given by,

(Cost incurred - Saving in public sector)/Total reduction of CO_2 emissions

= (236.98 - 230.93)/13992.45 x 1000

= Rs 432.37 per tonne of CO_2 saved in Carbon equivalent

= US $13.95 per tonne of CO_2 saved in Carbon equivalent (@ $1 = Rs 31.00).

Generally the projects which find favor with the Global Environment Facility (GEF) for funding are found to have the incremental costs per tonne of CO_2 removal of not more than US$ 25 (or US$ 92 per tonne of Carbon saved). In the case of MRTS if implemented in Delhi, the incremental cost per tonne of CO_2 saved in Carbon equivalent is estimated to be US $ 14 (approximately). This justifies a strong case for implementing the MRTS project in Delhi. The other benefits due to introduction of MRTS would be the cost and time savings due to decongestion effect.

Need for a unified metropolitan transport authority

Paradoxically, at all levels of government, central, state and local, no single agency has the authority, powers or institutional framework to ensure planning, coordination, budgeting, programming and phasing of urban transportation projects and controlling vehicular traffic. Multiplicity of agencies, linked with a multi-model urban transportation system, has been repeatedly identified as an issue of serious concern at numerous forums, but consideration, even in this respect, has been lacking. The National Transport Policy Committee (NTPC) *inter alia* recommended strengthening of transport facilities in metropolitan (cities with more than 1 million inhabitants), medium and small-size cities and considered issues like traffic management, institutional set-up, multi-model system, environment and energy conservation (*GOI, 1980*). In the absence of an integrated policy and coordinated approach, urban transportation has grown in response to demand in a haphazard manner. From 1987, the Ministry of Urban Development has been entrusted with the responsibility for urban transportation. The Ministry, however, does not possess the necessary expertise to direct urban transport planning. As of today, fragmentation and overlapping of responsibility and authority has made planning and management of urban transportation a complex task. To illustrate this, as many as 16 agencies (listed below) directly or indirectly influence the provision of transportation infrastructure, its operation and regulation in Delhi. These include. (1) Ministry of Surface Transport, (2) Ministry of Railways, (3) Ministry of Urban Development, (4) Directorate of Transport, (5) Delhi Police, (6) Land and Building Department, (7) Deputy Commissioner, Delhi, (8) Delhi Energy Development Agency, (9) Municipal Corporation, Delhi, (10) New Delhi Municipal Committee, (11) Cantonment Board, (12) Delhi Transport Corporation, (13) State Public Works Department, (14) Statutory bodies, (15) Delhi Development Authority, (16) Other private and public sector agencies.

Grounded in this vision, as recommended by the NTPC it would be essential that a Unified Metropolitan Transport Authority (UMTA) be established in a megacity like Delhi. Such an Authority will ensure effective transportation planning measures in Delhi, though no concrete action has been taken so far.

Transportation policy options and control strategies

In order to ensure a better balance between transport demand and supply in the context of Indian cities, especially Delhi, must aim at improving the public transport system by adopting select measures to reduce vehicular volumes. According to the strategy visualized for the Eighth Five Year Plan (1992-97), the emphasis has to be on the growth of mass transport ensuring environmental sustainability (*GOI, 1992*). Ultimately the solution lies in development of an integrated Mass Rapid Transit System (MRTS) for Delhi. Given the financial constraints, it is necessary to have integrated transport services by both the Public and Private Sectors in a harmonious manner to meet the growing demands.

The energy conservation efforts in the transport sector are especially weak. The fuel economy standards of Indian vehicles continue to remain poor compared to those in the developed nations. Poor vehicle maintenance, inefficient technology, poor fuel quality, greater vehicle weight and old tire technology are some of the causes of energy inefficiency in the road transport sector. For efficient energy use and control of vehicular pollution in Delhi, it is necessary to have a multi-pronged approach. This should be *inter-alia* addressed to the following tasks:

- Emphasis on mass transportation facilities
- Improving bicycle and pedestrian facilities
- Ensuring a smooth flow of traffic through proper traffic management
- Land-use transport policy directives for new developments
- Exploring and implementing the increased use of telecommunication systems
- Promoting car and van pooling through proper incentives
- Cost-effective technology development to increase the fuel efficiencies of vehicles
- Upgradation of fuel quality and use of cleaner fuel
- Prescribed emission standards for vehicles on road and at the manufacturing stage

Emphasis on mass transportation facilities

(a) Strengthening of public buses

In the situation of gigantic growth of traffic demand and road congestion, inefficient fuel utilization and severity of air pollution problem, availability of viable bus service is vitally important to the efficiency and efficacy of the transport system

Comparative analysis reveals that to meet each passenger kilometer of travel demand (*TERI, 1989*):

- a car consumes nearly 5 times more energy than that of a bus, while, two-wheelers consume about 2.6 times and three-wheelers consume 3 times;
- a car occupies 38 times more road space in comparison to a bus The corresponding figures for two-wheelers and three-wheelers are 54 and 15 respectively;
- the cost of operation of two-wheeler and three wheeler is 3 times, and car 10 times when compared to a bus;
- a similar advantage of bus is observed when emission level of CO, HC and NO_x are considered.

This suggests that mass transportation is vastly superior to personal and intermediate vehicles (taxis and three-wheelers). The desirable cost-effective solution to move people with fewer vehicles using less energy and less pollution could be achieved by increasing the share of mass transport based on buses.

As an illustration, it is estimated that an increase in share of buses in road transport from 66% to 80% in Delhi during 2001, would lead to a saving of 0.35 million tonnes of gasoline (*TERI, 1990*). The other advantages that ensue are over 50% reduction in total vehicles on the road, significant reduction in road congestion and reduced air pollution. However, diesel requirements will increase by about 8% (from 0.74 to 0.80 million kiloliter). But this too can be overcome to a sizable extent by improving the fuel efficiency of buses and improved traffic management measures with preference to buses, for example the provision of exclusive bus lanes. Also, to meet the total travel demand, 24,000 buses would be required in 2001. This means an additional 8,000 buses have to be added to the fleet strength by the turn of the century. At the present costs this would mean an additional investment of Rs. 4000 million. However, the net financial savings in fuel costs alone would amount to Rs. 8000 million annually in year 2001 (*TERI, 1994*).

(b) Implementation of MRTS

For the advantages of use of mass transport, policies must create conditions for development of commuter rail (MRTS) in the long-term, and buses in the short-term (1-2 years). Also, the mass transport system must ensure complementarity with the future MRTS/Ring railway in that they should furnish feeder services for the latter Further, mass transportation must become more flexible, if a major shift from personal vehicles is to occur. The key here is to recognize that potential transportation services are distinguishable by origin-destination pairs, time of day, comfort levels, and expected journey times.

The principal argument for price regulation or public ownership of mass transportation is that because of large sunk costs, these are "natural monopolies", and if left alone, can charge tariffs above average cost. However, in the case of bus services, the sunk costs (e.g., bus stops) are relatively small, and separable from other costs (e.g., capital costs of buses, wages, fuel).

One approach is for municipalities to construct and maintain as dense a set of bus stops/shelters as technically possible, freely accessible to all operators. Anyone wishing to operate bus services, raising capital from the market, may do so, without restrictions on tariffs, quotas, routes, comfort levels, or timings. Regulations must remain for safety, pollution, fuel efficiency, as well as qualifications of operators: driving skills and character antecedents. A tax on each bus may cover costs of bus stops/shelters and regulation. Economics suggests that under these conditions competitive markets for flexible bus services would emerge, with tariffs at about average cost (strictly, long term marginal cost), and supply matching demand. The resulting displacement of personal vehicles will also mean lower traffic congestion and pollution.

Flexibility of the mass transport system would reduce the use of personal vehicles for commuting. The additional benefits that may be expected include significantly reduced air pollution, road crowding, fuel consumption, and road safety.

Improving bicycle and pedestrian facilities

(a) Cycle traffic

In Delhi, an estimated 1.5 to 1.7 million person-trips are made daily by bicycle (*GOI, 1988*). Despite the importance of bicycles in the lower income households, little has been done to provide a safe and convenient ride to the commuters. Provision of proper bicycle paths on city roads - including exclusive bicycle tracks where density of bicycle is very high, merits serious consideration because bicycles are an energy saving and pollution free mode of transportation. In traffic management schemes, bicycle traffic should focus on activity nodes. Provision of bicycle parking at bus terminals and railway stations will help in promoting park and ride options for this group.

(b) Pedestrian facilities

Nearly 50% of the total trips in Delhi are exclusively pedestrian trips. While short-distance pedestrian trips are performed by all sections of society, long-distance walking trips are made mostly by economically weaker sections of the community. If urban transportation is the most neglected component of planned development, provision of pedestrian facilities is the most neglected aspect of transportation infrastructures. A zebra crossing for pedestrians is good in theory, but it has been observed that most drivers do not give right-of-way to pedestrians. Enforcement legislation is necessary to ensure the safety of pedestrians In order to ensure smooth and uniform surfaces for uninterrupted pedestrian movement there is a need to develop high-quality pedestrian facilities.

Traffic management measures

The primary reasons for setting up traffic lights in an urban network are not energy savings, but relate to concern for safety (dangerous crossroads) and smooth flow of traffic. On the other hand, the setting and where applicable, the synchronization of the various traffic lights in a network have significant energy implications. The importance of these implications depends on the control system adopted. Traffic control by means of traffic lights with improved traffic regulation systems and enforcement of traffic rules at crossroads makes it possible, for a given route, to achieve more fluid traffic flow; enabling more regular speed, reduction in travel time, the number of vehicle stoppages at crossroads, and total idling time, which all contribute to reduced fuel consumption.

Without the following measures the traffic light synchronization would be meaning less to improve smooth flow of traffic and thereby increase fuel efficiency.

- grade separation of fast and slow traffic, where possible
- exclusive busways at least along the main arterial city roads

- well designed arterial road intersections
- proper designed and maintained sidewalks and pedestrian crossings
- removal of all encroachments of pavements and roads.

Further, the congestion in some of the roads in the central business districts can be relieved by:

- restraints of parking of cars in congested areas
- area licensing fees for low occupancy vehicles entering congested areas
- staggering working hours.

(a) Parking management

Parking management is a most promising way to control vehicle trips to and from the congested areas of the city. Limiting the supply of on-street parking, regulating parking in the parking lots and denying it in "hot spot" zones and modifications in the parking price structure are some ways to reduce the total vehicle kilometers as also to discourage the use of personalized modes thereby effecting va shift to mass transport systems. A stringent enforcement of such regulations will generate additional revenues.

(b) Road pricing

A system of road pricing which has proved to be effective in some countries is the concept of area licensing, whereby low occupancy vehicles pay a charge for entering a congested area during the rush hours. The system encourages greater use of public transport and shared private cars or taxis and discourage avoidable journeys. Administrative feasibility of such a scheme in Delhi would need to be evaluated and details worked out.

Some of the tools that would help to achieve this are:

- Vehicle tax needs to be re-evaluated and modified to ensure that it captures social cost of the amount of road space occupied per passenger and pollution emitted by a vehicle per kilometer. The objective is not to unduly tax the vehicle user but to ensure that the potential capacity of the road system is utilized optimally A user tax may take the form of increasing vehicle registration fees, and toll on major facilities. One way that these restrictions may be accepted by the public is with a visibly improved mass transportation system.
- Higher gasoline price and lower diesel price to shift movement from private to public modes
- Price differential between peak and non-peak hours in mass transit systems. This would facilitate shifts of non-essential trips from peak to off-peak hours.

(c) Staggering working hours

Staggering of working hours could help traffic management in Delhi where a prominent peak hour traffic volume is noticeable. This measure has the dual benefits of spreading the load on both the roads and public transport systems. However, widely staggered working hours have not gained acceptance in the country mainly because commercial activities depend on interaction among various organizations and their workers. Nonetheless, the promotion of less widely staggered working hours by city authorities is desirable option considering the small cost involved.

Land-use planning

To ensure the generation of minimum per capita travel demand, proper land use planning is of utmost importance. The present practices promote large concentrated centralize business district (CBD). As the city size expands, the average per capita trip length and vehicle hours travel tends to increase. This is because the employment opportunities are concentrated in CBD. But the present level of congestion in CBD strongly suggests that alternative urban structures have to be adopted. Land-use planning must be so worked out that self sufficient neighborhoods are established so that the desired dispersal of population is ensured. The aim should be to minimize trip lengths and vehicle hours travel. Thus, the land-use should be so planned that the trips generated are within the carrying capacity of the overall transportation system network.

On the basis of empirical studies conducted in different cities it can be concluded that while planning new urban centers/urban expansion of an existing city the travel demand and hence energy for urban transport can be reduced by -

- adopting higher densities and clustering of land uses
- locating residential areas of workers employed in the service and trade centers in close proximity to their work places
- modifying zoning policies to allow for a greater mix of various land uses
- locating public service facilities close to intended consumers
- planning for a poly-nucleated urban structure with a large number of self sufficient neighborhoods linked by arterial highways.

Telecommunications

Viewing the level of demand for transportation as a function of the physical and economical arrangement of land-uses, suggests solutions based on a reduction of the magnitude and spatial spread of needed trips. Consideration is specifically needed in the following areas:

- Giving priority to development of telephone services to eliminate personal trips to collect information;

- Development of the telephone network for computer data transmission through use of satellite;
- Document transmission through facsimile/computer/telex networks.

These devices, as transport substitutes, already exist and possess immense potential for future development, provided they become freely available.

Technology development

There are a number of low cost technological options that could be readily adopted by Indian manufacturers that provide significant benefits in energy consumption and emissions.

For two-wheelers and autorickshaws, conversion to 4-stroke engines will result in a 35% fuel economy improvement, and a reduction in HC emissions by a factor of 10 (*Duleep, 1994*). This is an option for new vehicles and payback to the consumer occurs in 2 years or less at current gasoline prices. Other options include upgrading the 2-stroke engine with new technology for a 10-15% improvement in fuel consumption, which is possible even as a retrofit option.

In view of this, the widely prevalent two-wheeler technology of a two-stroke cycle engine needs to be discouraged. Production of fuel efficient four-stroke engines has been initiated at a small scale. The Government should give incentives for popularizing the production of four-stroke engines In fact, four-stroke technology should be made mandatory for two-wheelers of sizes 100 cc and above. Government tax policies should be re-examined to make fuel economy and not engine size, the basis for taxation, as larger engines can be both more fuel efficient and less polluting in many applications.

For diesel trucks and buses, Indian manufacturers are in the process of upgrading engine technology to obtain up to 10% better fuel economy. This can be aided by using radial tires for trucks and improving the quality of lubricants used in the engine, gearbox and axles to provide an additional 8-10% fuel economy benefit. Particulate traps and catalysts are good retrofit options for urban use diesel vehicles such as buses.

Given the high growth of diesel fuel use, technological improvements to diesel engines will be insufficient to curb diesel demand. India, with its large reserves of gas, should examine conversion to natural gas power, or to methanol derived from natural gas. Both fuels are better suited to spark ignition engines than diesel engines which require extensive modification for use with these fuels. Given the low cost of spark ignition engines relative to diesel engines, this option has started gaining much attention in India. This option may be particularly suitable for light-heavy urban delivery trucks and buses, and their use will result in large reductions in NO_x emissions and elimination of smoke emissions. In fact, some preliminary field test trucks of natural gas buses have already started in Delhi like other major cities.

Tax incentives to the manufacturers of fuel efficient vehicles will give a spur to such a program. In particular, buses need to be designed specifically for intra-urban travel. The efficient bus engine develops a torque at lower revolutions per minute and attains optimal fuel efficiency and emits less pollutants even at low cruising speeds. Further design modifications to reduce the weight of a bus and its aerodynamic drag need to be initiated. Production of such engines is necessary and should be so mandated in the near future.

Upgradation of fuel quality and use of cleaner fuel

The quality of fuel used in India is one of the worst as compared to the other developed countries. The pollution load from vehicular exhaust depend on the characteristics of fuel and efficiency of combustion. The main pollutants from gasoline include lead, carbon monoxide, hydrocarbon, and sulfur dioxide, the quantum of which varies with the quality of fuel burnt. High aromatic content results in increased emissions of hydrocarbons while high sulfur content increases the sulfur dioxide emission. Similarly, the exhaust from diesel driven vehicles carries significant amount of unburned hydrocarbon, oxides of nitrogen, carbon monoxide and sulfur dioxide. Through proper refining it is possible to have fuel with lower sulfur content

It is therefore a must to upgrade the quality of fuel through reduction of sulfur, tetra-ethyl lead and aromatic and cetane number Hydrosulfurisation units for reduction of sulfur content and catalytic reformer units for lead free petrol are required to be installed in the refineries. Increase in cetane number by 3 to 5 units will result in fuel economy and improvement in vehicular exhaust quality (*Biswas and Dutta, 1994*) Lowering of aromatic will also help in reducing emission of volatile organic compounds (VOC) during combustion.

Keeping these considerations in view, the Central Pollution Control Board (CPCB) has recommended that sulfur content in diesel to be reduced from 1 0% to 0.5%, with cetane number as 45 However, in the case of diesel, sulfur content be reduced from 0.25% to 0.15%.

Due to techno-economic reasons, the refineries are not in a position to introduce modifications in the process technology and install catalytic reformer units as needed for production of lead free gasoline. Hence, it has been proposed that the refineries should do the technology modifications in a phased manner so as to reduce the lead content to 0.15 g/l by 1995 and subsequent phasing out of lead to 0.03 g/l by 1997. It is also proposed that till such time the refineries, which are producing gasoline with high lead content, comply with the desired specifications Also, it should be ensured that metropolitan cities with high density of vehicular traffic are provided with gasoline with relatively low lead content. To reduce the consumption of leaded gasoline, it is proposed that the transport authorities should encourage the use of Compressed Natural Gas (CNG).

Prescribed emission standards

India has established limits on carbon monoxide emissions (at idle) for gasoline-fueled cars, motorcycles, and three-wheelers, and diesel smoke emissions at full load. Major elements include a 3% limit (by volume) on idle carbon monoxide emissions for all four-wheel gasoline-fueled vehicles, a 4.5% limit (by volume) on idle carbon monoxide emissions for all two and three-wheel, gasoline-fueled vehicles, and a 75 HSU limit on smoke density for diesel vehicles at full load (60 to 70% of maximum rated engine speed); the limit on free acceleration test is 65 HSU.

These standards went into effect on October 1, 1989. Automobile standards similar to ECU regulations 15-04 but tailored to Indian driving conditions went into effect in 1991. Diesel vehicle requirements were also tightened at that time.

Keeping these prescribed limits in mind, a test procedure has been established for periodic testing of emissions and imposition of penalties for non-compliance of standards. Public awareness campaigns have also been launched for encouraging proper driving habit and vehicle maintenance to meet the standards.

From the foregoing recommendations in the city of Delhi, it is evident that strong policy interventions need to be initiated to improve the vast scope for transport energy efficiency and the deteriorating environment.

Chapter 5. Sustainable transportation strategies in megacities

Motorization - the growth in ownership and use of motorized vehicles - inevitably leads to a range of air pollutant emissions to the atmosphere along with congestion and inefficient use of fuel. These in turn exacerbate both environmental and economic problems. As developing countries become more urbanized and increasingly dependent on private vehicles like, cars, motorcycles, and trucks, they will confront the linked problems of heavy traffic, urban pollution, high accident rates and low vehicle efficiencies. This problem is more acute in major cities, particularly the megacities of the world, where the air quality is deteriorating rapidly.

Significant intervention to control pollution from mobile sources started in developed economies in 1965 when legislation designed to actively combat air pollution from motor vehicles was enacted in the United States (U.S. Motor Vehicle Pollution Control Act). Subsequently, following the first energy crisis in 1973, developed economies started actively encourage energy efficiency in motor vehicles. By contrast, measures to reduce automotive air pollution and to encourage energy efficiency in developing economies have started only recently, although the degradation in air quality is as severe as, if not more in some cases, than in the industrialized economies. These developments suggest that there is a growing need for devising comprehensive sustainable transportation strategies for megacities in both developed and developing economies.

Through the use of case studies of two megacities - Los Angeles and Delhi - the efforts underway in developed and developing country cities to bring about sustainable transportation system is illustrated.

Comparative city profile

Appendix 5.1 gives the comparative profile of demographic structure, the transportation systems, energy use and emissions of the two megacities (Los Angeles and Delhi) for the period 1990. The major observations are.

1/ Delhi is experiencing a rapid growth of population as compared to Los Angeles. The average annual growth rate between 1980 and 1990 is 2.4% in Los Angeles and 4.7% in Delhi. While during 1984-90, the average annual growth rate of vehicles in both the cities are much faster than population growth (2.7% for Los Angeles and 14.4% in Delhi).

2/ Los Angeles is an automobile oriented low density (149 persons/sq.km in 1990) community with more than 87% of the daily commuters (6.8 million) travel by car. Delhi has over 95 times higher density of population (14313 persons/sq.km in 1990) with 15% of the daily commuters (9.6 million) travel by personalized modes, mainly scooters and motorcycles. The city of Delhi solely depends on buses for mass transport needs.

3/ Los Angeles has 17 times more cars per 1000 people than Delhi (32 cars per 1000 people). But, ownership of motorized two-wheelers in Delhi (128 scooters/ motorcycles per 1000 people) is 7.5 times higher than in Los Angeles. In Delhi, in recent years, the motor vehicle fleet grew by an average 14.4% per year. In contrast, vehicle fleet growth rate in Los Angeles in recent years have averaged only 2.7%. This suggests that the high relative growth registered in Delhi is likely continue as a result of currently low levels of per capita vehicle ownership, rising per capita incomes, and growing domestic motor vehicle manufacturing industries.

4/ Total per capita vehicle kilometers is nearly 1.8 times higher in Los Angeles. In 1990 total per capita motorized travel demand was 16875 kms, whereas in Delhi it was 9234 kms. Over 96% of the travel demand in Los Angeles is catered by personal vehicles (86% by cars and 10% by motorcycles). In contrast, more than 72% of the motorized travel is met by bus, and the share of personal vehicles is 25% (9% by cars and 16% by two-wheelers). Hence, Los Angeles has a far lower level of dependence on public transport service (825 bus km per person per year) This is over one-eighth the level provided in Delhi (6661 bus km per person)

5/ Nearly 49 million trips are generated daily (i.e., each person makes 3.4 trips) in Los Angeles, as against 12.7 million trips (i.e., 1.5 per capita daily trip rate) in Delhi. Only 27% of total daily trips are associated with commuting to and from work place in Los Angeles, of which over 72% of the trips are on Single Occupancy Vehicles (SOVs), 15% depend on car pool and only 5% use mass transport. In the case of Delhi, about 43% of the total trips are for commuting to and from work place and 31% for education purposes. Over 50% of travel in Delhi is by walking, 32% by buses, 9% by scooters/motorcycles, 6% by cars and remaining 3% by autorickshaw and non-motorized modes.

6/ Operating energy intensity of different transportation modes in Delhi is much higher (about 1.8 times higher in the case of car, 2.8 times in the case of motorcycles/scooters, and 6.3 times higher in the case of bus) than in Los Angeles. The operating energy intensity represents the fuel efficiency of different modes of vehicles. It measures the amount of energy needed to move 1 person over 1 km by a given vehicle. When these measures are averaged for an entire system, they are described as 'operating energy intensities' of a mode. Operating energy intensity of a vehicle, therefore is an average concept, which conceals wide variations in energy intake in operating conditions and is expressed in liters per passenger kilometer (l/pkm) (*GOI, 1980*).

7/ Transport energy and in particular gasoline use, is a powerful reflection of how much automobile dependence there is in a city. In 1990 the per capita gasoline consumption in Los Angeles was 1176 kgoe compared to only 52 kgoe in Delhi. In terms of total per capita energy use (i.e. including diesel) the corresponding figures are 1367 kgoe and 84 kgoe respectively. Such large difference in per capita transport energy consumption is in conformity with the strong negative correlation of urban density with gasoline consumption demonstrated in a research study of thirty-two principal cities of the world (*Newman and Kenworthy, 1989*).

8/ Annual emissions of CO, SO_x, NO_x, and SPM are very large in the Los Angeles basin as compared to Delhi. While air quality has improved dramatically in the basin over the past twenty years, the fact that the standards are now more demanding also leads to do even more despite the fact that the cost of doing more is very high. Ozone formed by the photochemical reaction of two motor vehicle exhaust emissions: NO_x and VOCs, is a major problem in the Los Angeles region. Despite the strict controls in the Los Angeles basin, maximum hourly O_3 concentration was 660 $\mu g/m^3$ in 1990 as against the federal standard of 235 $\mu g/m^3$ (value not to exceed more than once in a year). But, the local impacts of CO, SPM, lead and SO_2 on health and welfare are the most serious aspect of motor vehicle pollution in Delhi. This is due to a far larger population density and larger percentage of population moves and lives in the open air and is thus exposed to these automotive pollutants. CO concentration values at the major traffic intersections in Delhi have far exceeded the National Ambient Air Quality Standard (NAAQS). Similarly, concentration values of SPM mainly during the summer months (May-June) goes 3-4 times higher than the NAAQS. Also, relatively high levels of lead (0.58 gm/liter) and sulfur (0.25%) in Indian gasoline and relatively poor levels of vehicle technology and maintenance, have deteriorated the air quality in Delhi. These characteristics lead to serious emissions problems that can be reversed by raising fuel quality, vehicle technology levels, and maintenance requirements.

9/ On a per capita basis, the Los Angeles region burnt (1.02t C per capita during 1987) nearly 15 times as much carbon than Delhi (0.07t C per capita annually during 1990).

To ensure a sustainable transportation system in the Los Angeles region, the transport plan and policy document links the goal of sustaining mobility with the goals of fostering economic development, enhancing the environment, reducing energy consumption, promoting transportation-friendly development patterns, and encouraging fair and equitable access to residents affected by socio-economic, geographic, and commercial limitations (*SCAG, 1994c,d*). Moreover, Los Angeles's efforts for a sustainable transportation system are center stage because of the city's reputation as the most polluted city in the United States and as the automobile capital of the world (*Bae, 1993*). The air quality goals of the region appear to be driving transportation policy, primarily because the Air Quality Management District (AQMD) is the only agency with a mandate to enforce compliance.

The current air quality strategy in Los Angeles region, and megacities in developed countries in general, attempts to first stabilize emissions (from mobile and stationary sources) and then reduce them gradually. This strategy has emerged during the past three decades and is anchored primarily in regulatory standards and, to a lesser extent, in market-based incentives. The core of the strategy applied to mobile sources is two-fold· (a) setting emissions standards for fuel quality and engine technology, and (b) monitoring compliance with those standards through inspection and maintenance programs In addition to control measures, the transportation plan in Los Angeles have considered implementation of a number of land use planning measures through market-based incentives to reduce total vehicle miles travelled (VMT) and total vehicle hours travelled (VHT). Such measures as a mechanism to reduce travel demand and thereby energy use and pollution fall into three broad categories: (a) transportation demand management (promotion and support of ridesharing, ridematching, telecommuting, teleconferencing, mode shift, alternative work schedules, non-motorized travel, carpool); (b) transportation system management (traffic signal synchronization, ramp meter installations, Smart Streets operation); and (c) urban form (job-housing balance).

However, the case study of Delhi, where the nature of the problem and array of options are different from those in wealthier and more developed countries, suggests that the key elements of transportation strategy to support sustainable urban development, include: (a) improving vehicle fuel efficiency; (b) encouraging the introduction of cost-effective technological improvements to control emissions (c) introducing alternative fuels where these can be competitive with oil; (e) improving fuel quality; (f) strengthening mass transit system to obviate the use of highly energy intensive and costly personalized transport; and (g) improving traffic management measures and managing urbanization to reduce congestion.

Ultimately, the solution lies in building institutional capacity for transportation management in developing countries, while facilitating the co-development of advanced transportation systems by combinations of firms in the North and the South. Measures such as these, combined with high standards for new vehicles, inspection and maintenance programs for older vehicles, and land use planning strategies to facilitate the free movement of people (while minimizing the VMT/VHT) will help to maintain the momentum of development while limiting the environmental and social costs of transportation.

Sustainability as the new focus of transport policy

Sustainability involves three dimensions: economic sustainability, social sustainability and environmental sustainability and each of these are frequently mutually reinforcing Road or public transport systems which fall into disrepair because they are economically unsustainable, fail to serve the needs of the poor and often result in outcomes which are environmentally damaging.

While in principle highly controlled monopoly supply arrangements allows governments to direct the benefits of growth to poverty reduction and environmental sustainability, in practice this rarely occurs because of the inefficiency associated with monopoly supply. Reform of traditional policies and institutions is thus advocated, not because of any intention to subjugate social and environmental sustainability to growth, but because of the historic evidence that the economic unsustainability of heavily concentrated and regulated supply has actually prejudiced the achievement of social and environmental objectives. Institutional and policy reform is therefore the key to the economically, socially and environmentally sustainable provision of transport sector.

Environmental sustainability

The pattern of transport growth in the megacities associated with the process of development has generated some internal contradictions which threaten its environmental sustainability. Achieving sustainable transportation strategies is likely to mean different things in the context of developed and developing economies In developed economies, absolute reductions in the emissions of criteria pollutants from "on-road" vehicles in the face of growing vehicle travel, by using advanced pollution control technology, is a realistic goal. More difficult, but still technically feasible is the reduction of greenhouse gas emissions (especially carbon dioxide) to 1990 levels by 2015. Furthermore, use of renewable fuels and decreased dependence on fossil fuels are also technically feasible and, though potentially costly, well within the means of developed economies. However, in developing countries the state-of-the-art technological solutions to deal with manifested environmental problems are expensive and difficult to afford given the limited financial and economic resources available in developing countries. They should adopt cost-effective solutions to problems which vary by locality. Interventions therefore, must be selective, enforceable and affordable. In particular, they need to complement supply side interventions with demand management measures. These can be regulatory interventions. But given the need to finance the development and improvement of transportation alternatives, pricing mechanisms should be explored more actively.

The megacities in developing countries, need to develop their sustainable transportation system by considering three major elements. These include: (a) a greater focus on cost-effectiveness rather than state-of-the-art technologies; (b) an increased reliance on transportation demand management measures rather than exclusive attention to supply side interventions; and (c) adopting a more comprehensive and preventive package of longer term measures rather than the current partial and curative approach to the problem.

Grounded in this vision, the following section discusses the limitations of the present strategy and suggest ways to address them, with particular emphasis on developing economies.

(a) The importance of being cost effective

Global and regional pollution problems related to motor vehicle use include carbon dioxide emissions and ozone formation. At present these problems are primarily caused by the motorized transport fleets in industrialized countries. For example, emission of CO_2 and chlorofluorocarbons (CFC) from motor vehicles in developing economies contributes less than 3% to the global greenhouse effect. Of course, this share will grow as the developing country share of global use of motorized vehicles increases.

By contrast, local impacts on health and welfare are the most serious aspect of motor vehicle pollution facing less developed countries. It is important to note that automotive air pollution problems are not the same in all developing countries Like for instance, cities in the South and East Asia (such as Delhi, Bangkok, Manila, and many others) suffer from high levels of lead, particulate matter, carbon monoxide, and oxides of sulfur. In fact, the importance of two- and three-wheel motorized vehicles in South and East Asia is quite distinct from the pattern in OECD countries. Central and South American cities, such as Mexico city, and Santiago, experience frequent ozone problems, exacerbated by thermal inversion weather patterns which prevent dispersion.

The quality of fuels[1], engine efficiency, vehicle maintenance, traffic operations and emission control are all much worse in the developing countries, so the energy use and pollution output are much greater per unit of travel. Therefore, a cost-effective air quality strategy in developing countries will have to go beyond the choice of interventions based exclusively on the emission reduction potential under idle conditions per dollar of investment required. Hence, a cost-effective strategy needs to ensure that:

- the nature and magnitude of the problem is well defined. For example, in China and South Asia, mixed traffic with pedestrians and animal powered vehicles sharing the right-of-way with motorized traffic contributes to high idling times and suboptimal speeds for motorized traffic with concomitant increases in energy use and vehicle emissions;

- the emissions reduction objective is clearly defined;

- the choice of interventions is enforceable and affordable both financially and in terms of opportunity cost. Current Inspection and Maintenance (I&M) programs generally target entire fleets, using sophisticated and complex equipment, and on a routine basis. Evidence is increasingly showing that a small proportion of vehicles is responsible for a major part of the emissions and that even simple inspection procedures, randomly and selectively applied, can reap a substantial part of the gains achieved by more costly programs.

Attention to the criteria above will often result in a set of selective interventions tailored to the specific characteristics, needs and capabilities of the area, region or country where the problem must be solved. For the high-polluting vehicles, interventions should include in order of increasing cost (a) maintaining vehicles tuned-up (either through incentives or general public education programs), (b) retrofitting of engines, and (c) encouraging more rapid replacement if retrofitting is more costly than acquisition of newer vehicles complying with current standards.

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[1] Automotive fuels in developing countries are generally dirtier than those of developed countries, with lead content of gasoline as high as 0.8 to 1.1 g/lit, compared with 0.15 g/l for leaded fuel in developed countries. The sulfur content of diesel is in excess of 1.0% by weight, compared to 0.5% or less in developed countries.

(b) Increasing reliance on demand management measures

The current air quality strategy in developed economies is based primarily on a search for a technological fix. For this the developed countries are working towards zero emission or very low emission motor vehicles - i.e., combining the superior energy density of chemical fuels, such as hydrogen, with the emission free advantages of an electric motor - provided the electricity is generated by renewable energy sources. In the meantime the polluting fleet is large and growing and the focus is appropriately on a reduction in emission factors (pollutants per unit of transport activity) through enhanced fuel quality and improved vehicle engines. However, the growth in motor vehicle fleet, plus the increased average number of miles driven by more fuel efficient vehicles can partially or fully offset the improvements obtained from the increase in energy efficiency and the reduction in emissions output of individual vehicles. Thus, there are limitations to a strategy focused primarily on affecting automotive technology.

Demand management is critical for the current air pollution strategy, and needs to be more vigorously used than at present, having usually failed due to: (i) lack of public transport alternatives; (ii) lack of staff for design and enforcement; and (iii) political unwillingness to implement and enforce. To be most effective a range of restraint instruments need to be planned as part of a comprehensive transport strategy It is desirable, therefore, to complement the supply-side interventions with demand management measures if the ultimate objective is to secure improved levels of air quality Altering incentives is essential if social costs are to be internalized in private behavior. Measures directed at encouraging the development of alternatives to polluting, motorized transportation, reducing the need for travel or creating disincentives to excessive automobile use, are policy options that need to be considered and pricing has a critical role to play. Quantitative restrictions are occasionally appropriate. However, improved pricing is the preferred market-based approach as nobody disputes that it can perform the "win-win" role of both generating revenue for the implementation of much needed investments to improve air quality, and inducing a more environmentally friendly choice of fuels, vehicles and the extent of vehicle use

Pricing measures to signal the social costs of pollution and congestion are not widely accepted. In Europe and Japan gasoline prices range from \$3.00 to \$4.00 per U.S. gallon. In the United States and in developing countries prices are less than one-third to one-half of that range; they average about \$1.25 per gallon and vary from \$0.40 per gallon (in Venezuela) to \$2.60 per gallon (in India) (*World Bank, 1992*). Such international differences arise from differences in gasoline taxes. Many have advocated higher fuel taxes in the United States for the purpose of both recouping more of the social costs of automobile use and simultaneously encourage the use of alternative modes. As *David Greene* explains, "A 1¢ per gallon tax on gasoline in (United States) translates into over \$1 billion annually. A 1 mile per mile improvement in motor vehicle fuel economy would save consumers over $5 billion annually, and a 1% increase in the cost of a new motor vehicle amounts to over $2 billion per year. These are tiny change. Costs and benefits for the major changes that will be necessary to solve the transportation energy problem are truly heroic. Wise choices will be rewarded and mistakes will be costly (*Greene, 1994*)."

In the United States, roadways and automobile use have been massively subsidized. Auto users pay an artificially low price that reflects virtually none of the auto's enormous social and environmental costs. Moreover, roadway user taxes in the United States cover only 60% of the direct economic costs of roadway provision (*Pucher, 1995*). The overwhelming government support for automobile use in the United States has placed all forms of public transport at an unfair competitive disadvantage. In fact, car drivers should pay the "full cost" of their driving. Several policies are needed to promote such behavior, including rescinding subsidies to automobile manufacturers as well as for highway construction. Vehicle and gas tax generally do not pay for a fraction of infrastructure. Full-cost pricing means the internalization of all environmental, social, and health costs. Use of the full-cost principal in cost-benefit calculations and of "polluter pays" principle, including road user fees, would help greatly to slow the growth in vehicle-kilometers traveled. In other words, taxing polluters is the most economically efficient solution (*Greene, 1994*). Raising gasoline prices closer to their full costs may be almost as effective as regulating fuel efficiency standards in reducing currently externalized environmental costs. The U.S. improvements in fuel economy from 17 miles per gallon (mpg) in 1976 to 28 mpg in 1986 was in part achieved from the tripling of gas prices between 1973 and 1980 (*Goodland, 1994*).

According to *Martin Wachs*, one of the most intriguing proposals involving gasoline prices in the United States would be to shift the burden for paying part for the automobile insurance to the form of a per gallon charge at the pump (*Wachs, 1993*). Such a plan would have several benefits. First, it would respond to the problem of uninsured motorists in Southern California, where it has been estimated that approximately 25% of automobiles on the road are in violation of the law requiring them to be insured. Secondly, such a program would add an element of equity to the system of charging for insurance which is now based largely on geographic location of residence rather than use of the vehicle. Finally, the insurance premium in the form of a gasoline surcharge, by raising the unit cost of driving rather than treating insurance as a fixed cost,would contribute to the increased attractiveness of alternative modes in relation to the Single Occupancy Vehicles (SOVs).

In developing countries, domestic fuel prices are rarely high enough to reflect the wider environmental costs of vehicle usage. In other cases, prices of leaded fuel are lower than that of unleaded fuel thereby stimulating misfueling and undoing the benefits of introducing catalytic converters. Parking charges and other market-based forms of restricting car use are also not very common, in part because reliable public transport options are not available.

The process of identifying appropriate forms of demand management is not simple, even for non-price measures, and there is a need for more experimentation to tailor measures to country and culture-specific conditions, as not all measures work equally well. For example, traffic bans in the form of odd/even car license number restriction have been tried in Athens, Mexico City, and Santiago with mixed success. In Athens, the number of households with two cars increased and motorists who were not allowed to enter the city center drove around the city to get near their destination thereby increasing the length of their trips and increasing emissions (*Cragg, 1992*). In Mexico city and Santiago, the daily restriction on traffic is becoming less effective as a result of the rapid increase in vehicle ownership and use, as well as the exception granted to automobiles equipped with catalytic converters.

Use of market instruments in demand management has the advantage over a purely administrative approach that they allow decentralized decision making to select the form of adjustment best suited to the individual preferences. While the calculation of "right prices" of externalities remains controversial, several pricing instruments can be considered. Higher prices of fuel have been a component of comprehensive strategies for controlling the impact on the environment in countries such as Mexico, Thailand and Indonesia. This can be supplemented by increased parking charges, as currently being implemented, for example in Korea and Poland.

(c) Comprehensive and preventive package to improve urban structure

The current trends of urbanization and motorization in developing countries in many ways follow a similar path adopted by the developed economies. However, despite a deceleration in growth rates relative to those experienced at the beginning and middle of this century, the dependency on motorized vehicles is still growing in developed countries. With the continuing growth in urban populations, residences are increasingly locating on cheaper land in the urban periphery. This results into a substantial decentralization of employment and an increase in the number and length of vehicular trips with more and more dependence on personalized vehicles. Given this evolution in the industrialized economies, the principal developmental strategy questions that arise for developing countries are the following: *Whether the developing countries need to follow the development pattern of developed countries associated with the heavy dependency on the automobile? Are there policy mistakes and/or environmental costs in this pattern that can, and should, be avoided? What are the policy implications?*

Experience worldwide suggests that government intervention in the area of transport-related air pollution tends to start very late, when pollutant concentrations reach intolerable levels for the urban population of the megacities. The current two-step sequence - of initially stabilizing emissions and then gradually reducing them - is essentially a crisis response strategy. By then, land-use patterns and the modal dominance of the automobile are difficult to undo, even in the medium term, hence the need to endure "sub-optimal" air quality for long periods of time. In short, interventions are more partial and curative rather than comprehensive and preventive.

Difficulties have been encountered in implementing effective measures to reduce the reliance on polluting, motorized vehicles in existing megacities. There is no reason why lessons should not be drawn now from this and applied to the next generation of secondary cities which are growing rapidly. To manage the process of motorization and its associated environmental impacts, a cost effective long-term strategy needs to be devised, which would involve identifying and implementing policies and measures. Such a strategy would have to include, amongst its many components, paying substantially greater attention to preventive actions such as better strategic land-use planning and greater reliance on a more effective multimodal transport system.

There is a need, therefore to develop a broad consensus and commitment to experiment with promising options, such as the role of Mass Rapid Transit (MRT) into the urban structure. For corridors with high traffic volumes mass rapid transit is more economical in the use of space and less environmentally damaging than urban transport dependent exclusively on the automobile. But there is a curious "Catch 22" situation that has afflicted many MRT proposals. When cities are small the corridor flows are not sufficient to justify MRT systems. By the time they have grown to the stage at which the likely traffic volumes seem adequate the urban structure has already developed to the stage at which the superimposition of an MRT network is excessively costly in terms of the capital cost, land acquisition, system construction as well as operating and maintenance cost.

With the external effects of road transport underpriced it is very difficult for any metro to be financially viable. There are a range of ways in which external beneficiaries from the existence of a public transport system may be charged. Auto purchasers may be required to purchase a public transport bond as in Korea. Car users may be required to contribute part of the fuel tax for public transport. Property developers may be required to contribute to public transport development costs, as in London Dockland Railways. Any method chosen must have substantial public support and be compatible with the national legal system.

Caution about metros is appropriate where there are more viable alternatives. For medium and large cities where the bus is the backbone of mass urban movement, such as Delhi, segregated busways have proved able to carry high volumes at acceptable speed and at a fraction of the cost of metros. Experience suggests the possibility of a phased approach (as planned for Karachi) in which, at an early stage in the city's development, an adequate right-of-way network would be protected for urban transport corridors identified well in advance of city growth, to be upgraded sequentially to the carrying capacity of the corridor (initially for dedicated busways, eventually light or medium rail, and ultimately full metros) as economically and financially justified to meet an increasing public transport demand. Increased emphasis on rail thus requires integration into land use schemes; public support by internalization of external costs, which would increase the relative costs of road transport; and adequate provisions for modal coordination and interchange. Such a long-run land-use strategy does require a capacity to plan and willingness to commit to an urban structure which is rare. The absence of such a comprehensive institutional framework has proved very damaging in such cities as Delhi, Bangkok, where the need for MRT is appearing to be most obvious.

Social sustainability - poverty reduction

In urban areas the principal - and usually the only - resource of the poor is their labor. The primary function of transport is thus as the means of access from the home to the work place. In practice excessively long journey times are found in major cities in most continents. Where incomes are very low in comparison to transport costs this will also involve a high proportion of long walking journeys to work and in some cases the use of public transport. To an increasing extent sustainability of poverty reduction and minimization of adverse environmental impacts must be built in to transport strategies and policies in ways which are consistent with the general liberalizing and commercial thrust of the policy reforms.

(a) Non-motorized transport

In medium sized towns in India, between 50 and 80% trips are by non motorized transport (NMT) modes. In Delhi, 65% of people living in squatter areas walk to work, compared to 10% of low income and only 3% of middle income workers. Because of this high level of dependence of the very poor on NMT and because of its benign influence on the environment, improvements of NMT are amongst the best focussed ways of helping them. The most dramatic improvement in this respect would be a shift from walking to cycling. For passenger transport cycling offers speeds and effective ranges of movement at least three times as great as walking, and can continue to play a role as an efficient and environmentally benign local distributor even in high income situations. Despite this potential, NMT has been disadvantaged, as it has suffered from being very dangerous. This is largely due to the failure to separate fast and slow moving traffic adequately -the absence of sidewalks for pedestrians and of cycle paths being common defects. This calls for more explicit consideration of the financing of separated right of way and facilities for NMT (and particularly its safety) in major infrastructure development schemes. Transport policies should reduce prevalent disincentives for walkers and maintain sidewalks along the road corridor.

(b) Urban public transport

Megacities already face major problems. Many secondary cities are also developing rapidly. The importance of urban transport projects is therefore likely to increase. The aim in urban transport should be to create a more even market framework which allows the different modes of transport (including non-motorized transport) to find their appropriate role. This requires that public transport be liberalized and public monopolies in service supply eliminated. Private use of publicly provided infrastructure should ideally be charged at levels representing the marginal costs, including both congestion and environmental effects.

The pursuit of such policies requires public regulatory action or to manage the achievement of social objectives. Moreover, neither congestion pricing, nor an effective surrogate, exists in most cities. Until these conditions are achieved, a balanced "second best" package of measures will be required within which public transport fare increases are limited to those necessary to ensure the sustainability of public transport services (i.e. coverage of operating and vehicle replacement costs).

In some cases, particularly where radical political and economic change has increased transport costs for the poor without increasing their incomes, some form of support may be required. If that cannot be achieved through direct income transfers it may be necessary to subsidize transport. Policy on urban public transport subsidy must take into account the fact that commercial transport systems can only be financially and economically sustainable if they are also affordable to users.

Where the problem is well-defined geographically, subsidy may be directly targeted by route Where deprivation is geographically more diffused, income supplements are preferable to payments in kind. But direct income transfers to the poor may be difficult to organize where there is no adequate basis for income recording and verification, and well targeted support may involve the use of subsidies on journeys to work tickets channelled through either the employer or operator, as in the Brazilian "vale transporte" scheme. Effective subsidy thus requires both an adequate budget and an administrative procedure for the disbursement of that budget.

(c) Spatial relocation and resettlement

New transport infrastructure can involve forced resettlements which can, in turn, lead to great hardship if adequate resettlement and compensation arrangements are not made. The appropriate policy on resettlement for transport projects is not to avoid any project involving resettlement (which would exclude some with very large benefits) but to focus instead on ensuring standards of treatment of those affected which eliminate hardship for the displaced.

Economic sustainability

The costs of maintaining excessively large networks and subsidized operations of poorly managed public enterprises in transport frequently accentuate fiscal crisis in developing countries and are ultimately unsustainable. Inadequate finance often leads to reduction of maintenance expenditures for transport infrastructure, with consequent decline in service quality.

Economic sustainability requires adequate finance for maintaining infrastructure and equipment to ensure that potential benefits from infrastructure actually accrue. All projects and programs should therefore be accompanied by a committed pricing and/or financing package adequate to ensure the maintenance of the asset through its effective economic life.

Infrastructure tolls (direct user charges) are an alternative source of finance These generate revenue but may distort utilization patterns where surrounding networks are dense and congested. Private sector finance and management skills can also be brought to transport infrastructure through concessions to private companies to build and operate infrastructure which will ultimately be transferred to public ownership. Built operate and transfer (BOT) schemes may offer a means of escaping public sector financial constraints, often through associated land development rights which enable the development gain to be mobilized for transport infrastructure finance purposes.

Emission control measures

There is an immediate need to improve the monitoring and emissions inventory capabilities of the megacities in the developing countries. These are prerequisites for sound air pollution management strategies aimed at protecting public health. Therefore, simple and rapid techniques for air quality monitoring and assessment should be investigated and applied where appropriate.

Inspection and maintenance programs

Vehicle Inspection and Maintenance (I/M) programs have been an integral element of air pollution control programs in many industrialized countries, but special care is required in designing the inspection and enforcement mechanisms of I/M programs in developing countries.

Two types of I/M programs are common: centralized programs, in which all inspections are done in high-volume test facilities operated by the government or by a private government contractor, and decentralized programs, in which both emissions testing and repairs are done in private garages. The decentralized arrangement is much less effective because of fraud and improper inspections. Centralized programs operated by contractors generally yield the best results (*Weaver, Faiz and Walsh, 1994*).

I/M programs help identify equipment defects and failures covered by vehicle warranty schemes. The programs also discourage tampering with emission controls or misfueling. Where emission standards have recently been introduced, measures are needed to address existing uncontrolled and high-emitting vehicles. Retrofit programs for some vehicles may reduce in-use emissions. Policies that accelerate the retirement or relocation of worn-out and inefficient vehicles and vehicles not equipped with emission controls can also be of value, particularly in developing countries where the high cost of replacement vehicles and the low cost of labor for repairs result in large numbers of older vehicles in service.

Available data suggest that a well-run I/M program can bring about very significant emissions reductions - about 25% for HC and CO and 10% for NO_x (*Sathaye and Walsh, 1992*) The less significant NO_x reductions reflect solely the lower tampering rates from I/M and anti-tampering programs, since at present there has been no focused effort to design I/M programs to identify and correct problems that specifically cause excess NO_x emissions.

For existing vehicles, given the higher average age of vehicles in developing countries (10-15 years), the issue of vehicle maintenance control is most challenging. Enforcement of mandatory regular inspections has already been started in Chile, and similar provisions are being made in urban transport projects in Indonesia and are being considered in Costa Rica. Intensification of random roadside inspections has been implemented in major urban areas of Taiwan, India, and Thailand by the local environment protection agencies, but would become more effective if the combination of inspection rate and penalty enforcement is well chosen. These measures require the creation of specialist institutions with adequate equipment and trained staff, which typically do not exist in the poorer countries. The World Bank has supported the development of capacity to monitor and control emissions in Thailand, Sri Lanka, Mexican medium size cities and in Sao Paulo.

In a typical I/M program, the reductions start out slowly and gradually increase over time, because I/M programs tend to lower the overall rate of fleet emissions deterioration. Thus, maximum I/M benefits are achieved by adopting the program as early as possible.

Although I/M programs can reduce emissions from the worst vehicles in the existing fleet, emissions are nonetheless likely to remain unacceptably high because of the large number of uncontrolled vehicles already in existence. Where the severity of the air quality problem warrants it, therefore, it may be appropriate to consider vehicle retrofit and replacement programs. Such measures are likely to be most cost-effective when applied to intensively used vehicles such as taxis, minibuses, buses, and trucks.

Vehicle replacement

Vehicle replacement is generally the most practical solution where the existing vehicle fleet is old, in poor condition, or (as in the case of taxicabs) difficult to retrofit. Such replacements can not only reduce emissions, but can improve traffic safety. For instance, in Mexico City a taxi modernization program is underway. The aim is to replace all pre-1985 taxis with new vehicles meeting Mexican 1991 or 1993 emission standards. This program includes a combination of regulatory measures (taxicab licenses will be denied for pre-1985 vehicles) and economic incentives. As an another example, Hungary has taken a step that businesses that own two-stroke engine vehicles will have to scrap them. However, individuals will be encouraged to replace two-stroke vehicles with four-stroke engines or even install catalytic converters for the two-stroke engines. In the case of buses and minibuses, it can also improve the quality and comfort of public transport - possibly helping to encourage a mode shift from private cars.

However, a key concern in evaluating the cost-effectiveness of a vehicle replacement program is the disposition of the vehicles replaced. If the old vehicle is allowed to continue operating as before (with a different owner), emissions will not decrease. Requiring the old vehicle be scrapped ensures that the full emission reduction is achieved, but may greatly increase the cost of the program, depending on the old vehicle's value A less costly alternative is requiring the old vehicle be sold and re-registered outside the urban area - thus increasing the supply of transport in rural areas and ensuring that the vehicle's emissions do not add to pollution in the city (*Weaver, Faiz and Walsh, 1994*).

Retrofit programs

Retrofitting emission controls may be the most cost-effective option for reducing emissions when a vehicle remains in reasonable condition but was manufactured without emission controls. Depending on the situation, this retrofit may be accomplished by installing additional components, such as air pumps or catalytic converters. In Hungary, the government has initiated a five-year program to persuade owners of older cars to install catalytic converters and will offer financial assistance (up to 60% of the cost of retrofitting with catalytic converters) (*Walsh and Karlsson, 1990*).

Retrofit strategies are especially appropriate for heavy-duty vehicles such as trucks, buses, and minibuses. This is because these vehicles have high levels of emissions, long lives, and high usage levels, so retrofitting improves their cost-effectiveness. For medium- and heavy-duty gasoline vehicles, one practical and effective means of reducing emissions is to convert them to burn liquified petroleum gas (LPG) or compressed natural gas (CNG). This can result in substantial reductions in emissions. These fuels also offer substantial savings in most cases, since both LPG and CNG are less costly than gasoline and are frequently available from domestic resources. Natural gas is usually cheaper than LPG and has superior characteristics as an engine fuel.

An example of a large-scale emissions retrofit program is underway in Mexico City. The Environmental Commission for the Mexico City Region has developed a plan to retrofit more than 100,000 gasoline-fueled minibuses and gasoline trucks with LPG and CNG systems. Vehicles to be retrofitted will be those built between 1977 (1982 in the case of minibuses) and 1991 (when catalyst forcing emission standards of gasoline vehicles came into effect). Some pilot studies on CNG based medium and heavy-duty vehicles are also underway in major cities of India.

Policy and institutional reform as the main route to sustainability

The key to improvement in the transport sector remains the availability of a basic infrastructure. The main infrastructure networks - particularly road and rail networks - remain in the public sector and will continue to make demands for resources. Beyond that, however, there are new policy implications and the need to ensure transport provision which is economically, environmentally and socially sustainable. The core infrastructure must be properly maintained; low cost public transport services of adequate quality must be provided for those dependent on them; the adverse environmental impacts of transport must be contained.

Past failure to meet these requirements has been partly a human resource problem, as governments do not possess adequate skills to perform the planning and control tasks required of them. But it is also institutional in so far as governments continue to rely on mechanisms making unrealistic demands on human resources and motivations. For that reason it is necessary to find new means of ensuring that transport provision is responsive to user needs.

First, market supply must be truly competitive. The primary thrust of policy must therefore be to create and sustain a competitive market. Private sector initiative can be mobilized through competition, either within the market (where there are few economies of scale) or for the right to supply the market (where economies of scale dictate more concentrated supply). This requires regulatory reform which developing countries may find difficult to achieve due to their existing institutional weaknesses. Regulatory frameworks must be revised to ensure protection of environmental and social priorities, while allowing market incentives to encourage efficient service delivery. Regulatory reform requires human, institutional, and financial resource development. The main thrust of regulatory reform is to give greater freedom of entry into markets and of operation within markets. In some cases (for example, control of vehicle overloading, vehicle safety, and road use behavior) regulatory improvement is largely a matter of strengthening existing monitoring and enforcement capability. In other cases (for example, environmental impacts of new infrastructure investment) it involves setting up participatory development and appeal processes.

Second, all of the costs and benefits to society must be taken into account by the supplying agencies in making commercial decisions. Prices for the use of infrastructure must cover the costs of its provision.

The general strategy involves a complex institutional agenda containing the following elements:

- deregulation to create the framework for a competitive market, and associated supervision of market behavior to maintain user responsiveness;
- increased private sector participation in supply within those markets;
- commercialization of many remaining public sector functions, including increased user participation in objective setting and management;
- environmental management to avoid adverse impacts of markets, and
- targeted poverty reduction to contain adverse distributional effects

In the coming century, the number of megacities will continue to increase. Between 1970 and 2000, the number of cities with populations of more than 10 million will have increased six-fold, from 4 in 1970 to 24 in 2000. In 1970, there were 35 cities of more than 3 million people; today, there are 69 of them, and in 2000, the United Nations estimates, there will be 85. By 2025, this number could well have doubled (*United Nations, 1989*). Of the 69 cities that currently have more than 3 million people, 45 are in developing countries, and many are likely to become megacities.

By studying the energy use and emissions due to "road-based" motorized vehicles for meeting growing travel requirement in the two very different megacities in the United States (Los Angeles) and India (Delhi), and sharing experiences, it is hoped that the megacities of future may be able to avoid repeating mistakes of the past and would help economists, energy planners, transport specialists, and environmental staff to think more clearly and constructively about the links between transport energy use and environment and about the design of policies and programs for sustainable urban development.

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Appendix 3.1. Number of vehicles registered in different counties

Year	County/Region	Auto	Truck	M-Cycle	Total
1960	Los Angeles	2772523	297762	27649	3097934
	Orange	309392	32456	3487	345335
	Riverside	126080	22025	2306	150411
	San Bernardino	205472	32060	3285	240817
	Ventura	76582	13054	889	90525
	All together	3490049	397357	37616	3925022
1970	Los Angeles	3670496	477075	183444	4331015
	Orange	748217	95107	45509	888833
	Riverside	223570	45023	15378	283971
	San Bernardino	319870	65547	23622	409039
	Ventura	180946	31154	11787	223887
	All together	5143099	713906	279740	6136745
1980	Los Angeles	4048996	743629	192902	4985527
	Orange	1181374	235726	65463	1482563
	Riverside	352464	111661	23210	487335
	San Bernardino	457624	178521	34993	671138
	Ventura	295212	83832	20820	399864
	All together	6335670	1353369	337388	8026427
1984	Los Angeles	3872369	773329	163064	4808762
	Orange	1162684	232613	56187	1451484
	Riverside	370480	119124	20944	510548
	San Bernardino	469470	152801	30221	652492
	Ventura	303337	74808	18223	396368
	All together	6178340	1352675	288639	7819654
1987	Los Angeles	4586509	1001340	167980	5755829
	Orange	1402485	313183	57917	1773585
	Riverside	481540	168320	23399	673259
	San Bernardino	606962	218550	32652	858164
	Ventura	369467	105561	18910	493938
	All together	7446963	1806954	300858	9554775

Appendix 3.1. Number of vehicles registered in different counties

Year	**County/Region**	**Auto**	**Truck**	**M-Cycle**	**Total**
1990	Los Angeles	4817814	1149017	147464	6114295
	Orange	1486200	364128	50715	1901043
	Riverside	601555	228612	24161	854328
	San Bernardino	718369	282565	31421	1032355
	Ventura	398425	125067	17010	540502
	All together	8022363	2149389	270771	10442523

Source: *California Department of Transportation, 1994.*

Appendix 5.1. Comparative chart for the two megacities in 1990.

Description	Unit	Los Angeles	Delhi
Demography			
Population	million	14.6	8.5
Annual growth rate (1980-90)	%	2.4	4.7
Area	sqkm	98382	592
Population density	persons/sqkm	149	14313
Growth of vehicles			
Number of registered vehicles	million	10.4	1.9
Car	%	76.8	21.7
Motorcycle/Scooter	%	2.6	68.0
3-wh (autorickshaw)	%	-	3.6
Bus	%	na	1.1
Truck	%	20.6	5.7
Annual growth rate (1984-90)	%	2.7	14.4
Car	%	4.9	21.6
Motorcycle/Scooter	%	-1.1	17.8
3-wh (autorickshaw)	%	-	18.4
Bus	%	na	7.1
Truck	%	8.0	15.4
Vehicle ownership pattern			
Cars per 1000 people	number	544	32
Motorcycles per 1000 people	number	17	128
Travel parameters			
Annual total per capita vehicle kilometers	km/cap	16875	9234
Car	%	86.1	9.4
Motorcycle/Scooter	%	10.0	15.9
3-wh (autorickshaw)	%	-	2.5
Bus	%	4.9	72.2

Appendix 5.1. Comparative chart for the two megacities in 1990.

Description	**Unit**	**Los Angeles**	**Delhi**
Daily total per capita trip rate	trips/capita	3.4	1.5
Work	%	27	43
Education	%	na	31
Other	%	na	26
Daily total commuters	million	6.8	9.6
Mass transit	%	5	32 5
Personalized vehicles	%	87	15 4
Work at home	%	3	-
Walk only	%	3	50
Other	%	2	2.1
Transport energy use for passenger travel			
Fuel consumption pattern			
Car	km/l	9.2	10
Motorcycle/Scooter	km/l	21.3	45
3-wh (autorickshaw)	km/l	-	20
Bus	km/l	2.54	3
Operating energy intensity			
Car	l/pkm	0 07	0 0385
Motorcycle/Scooter	l/pkm	0.0391	0.0139
3-wh (autorickshaw)	l/pkm	-	0.0278
Bus	l/pkm	0.0406	0.0064
Total energy demand	mtoe	20	0.71
Gasoline	%	86	62
Diesel	%	14	38
Gasoline: Annual growth (1980-90)	%	1 05	9.97
Diesel: Annual growth (1980-90)	%	na	6 86
Annual per capita energy use	kgoe/capita	1367	84

Appendix 5.1. Comparative chart for the two megacities in 1990.

Description	Unit	Los Angeles	Delhi
Annual mobile on-road emissions[1]			
CO	mt	1.59	0.18
SO_x	mt	0.01	0.002
NO_x	mt	0.24	0.02
HC	mt	-	0.073
SPM[2]	10^3 tonnes	19.35	0 36
Pb	10^3 tonnes	-	0.10
ROG	mt	0.22	-
CO_2	mt of C	15.07	0.70
Annual per capita CO_2 emissions	tonne of C	1.02	0.07

[1] for Los Angeles, data pertains to 1987.

[2] for Los Angeles particulate matter with a diameter of 10 micrometer or less is considered.